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A STUDY OF SOME ALBERTA SOILS UNDER DIFFERENT DRAINAGE CONDITIONS

J. A. McKeague

University of Alberta

April, 1958

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A STUDY OF SOME ALBERTA SOILS UNDER DIFFERENT DRAINAGE CONDITIONS

A DISSERTATION

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
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by

J. A. McKEAGUE

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ABSTRACT

There were two aspects to this study:

1. A comparison of morphological and certain chemical characteristics of gleyed soils with strongly eluviated horizons and associated well drained soils.
2. A laboratory investigation of soil material set up under different drainage conditions.

The gleyed soils, which have been referred to in Alberta as Slough or Depression Podzols, were sampled in depressions over a large area of the province. They are compared with associated Chernozemic and Podzolic soils. Chemical analyses revealed no major differences between Slough Podzols and associated Podzolic soils. Several morphological differences are indicated. Results of the laboratory study indicated that redox potential fluctuations throughout the year may be much greater in Slough Podzols than in associated well drained soils. This would be an important difference with respect to soil development and plant growth. The classification of Slough Podzols is discussed. Eluviated Glei is suggested as a name for these soils rather than Slough Podzol or Grey Wooded Glei. Some subdivisions of Eluviated Glei are suggested at the category IV level.

The laboratory study involved measurements of the effects, on redox potentials and on composition of the leachates, of subjecting soil material, with and without organic matter added to the surface, to various drainage conditions. The soil was contained in four inch by five inch rectangular plastic columns 20 inches high. Eh was markedly lowered by high water table conditions when leaves were present at the surface. When no leaves were at the surface, high water table had no effect on Eh. Low Eh was associated with high iron content of leachates. Amounts of other ions determined were not affected by drainage conditions. In the two columns where soil material was mixed with Ottawa sand, there was clear evidence of downward movement of soil and accumulation in irregular bands.

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A STUDY OF SOME ALBERTA SOILS UNDER DIFFERENT DRAINAGE CONDITIONS

I. INTRODUCTION

Studies of soil genesis are concerned with investigations of the conditions and processes which lead to the development of certain profile characteristics. Such studies are less easily justifiable from an immediately practical standpoint than are enquiries into matters related to soil fertility and soil conservation. However, a knowledge of the factors involved in the genesis of soils is fundamental to all branches of soil science. Robinson (44) stated, "the study of the genesis and constitution of soils and the development of a philosophical system of classification will yield, as corollaries, practical results that could hardly be obtained by direct search."

Apart from the basic purpose of seeking fundamental information, soil genesis studies are likely to yield results of immediate value. Soil genesis and soil classification are so interrelated that any discovery in one field is sure to be of use in the other. As man exercises an increasing degree of control of the environment, knowledge of soil genesis will be useful in predicting the effects on the soil of changing such factors as climate and vegetation. Furthermore, information on the genesis of soils is useful to workers in related sciences such as ecology and geomorphology.

There are two basic ways of studying soil genesis: the field or observational method, and the laboratory or experimental method. Most studies involve a combination of these approaches. The field method involves the inspection of a number of soil profiles in an area and an attempt to explain variations on the basis of observed differences in climate, vegetation, relief, and parent material. The basic generalization of early Russian workers that climate has a dominant influence on soil formation was a result of this approach. In the experimental method of studying soil genesis, controlled experiments are carried out on soil material. Analyses are done to determine the nature and rate of changes that occur. This approach has the advantages that conditions can be controlled, processes accelerated, and changes measured at any stage. However, artificial laboratory conditions may differ in some important aspects from the natural environment under which soils form. Furthermore, changes may occur very slowly. Many soil genesis studies involve the analyzing of field samples and theorizing on the results. Such studies show the present state of the soil but the processes by which the soil arrived at that state must be inferred.

It is logical that the major emphasis in soil genesis studies is placed on the soils of greatest extent and agricultural value. Thus, in Canada, more is known about

zonal than about intrazonal soils. The characteristics of Black, Brown, Grey Wooded and Podzol soils have been widely studied and much is known of the genesis of these soils. Considerably less is known about poorly drained soils, particularly in Western Canada. The distinctive characteristics of some of these soils are not well enough known to make possible an adequate classification of poorly drained soils.

More information on the characteristics and development of poorly drained soils is desirable. Such soils will be more extensively cultivated when the diminishing area of well drained arable soil is all under cultivation. Localized areas of poorly drained soil occur on many farms in the Black, Degraded Black, and Grey Wooded Soil Zones in Western Canada. Usually the poorly drained spots are markedly less productive than adjacent well drained soil. Information on the nature and genesis of poorly drained soils is essential not only for agronomic reasons but for an understanding of soil and for the development of an adequate system of classification.

II. REVIEW OF LITERATURE

A. Studies of Poorly Drained Soils

Poorly drained soils are characterized by strong evidence of gleying in the soil profile. Common morphological features of gleyed soils are:
(a) a grey to bluish grey, sticky, massive horizon in the profile, and (b) mottling and iron staining. These features are expressed in varying degrees. Permanent waterlogging results in the formation of a distinct glei horizon. A fluctuating water table gives rise to mottling in the temporarily saturated portion of the profile.

Gleyed soils are local rather than regional in distribution. Joffe, (31) states, "Glei is a hydrogenic, not a climatogenic formation". Small areas of gleyed soils are distributed throughout many soil areas. They are very common in regions of Podzolic soils, but they also occur in conjunction with the Black and Brown Zones, in wet areas of the tropics, and over relatively large continuous areas of tundra.

The classification of gleyed soils is not as clearly defined as that of zonal soils. Under the United States system of classification outlined by Thorp and Smith (55) gleyed soils are classified as follows:

Order	Suborder	Great Soil Group
Intrazonal	Hydromorphic	Humic Glei Low Humic Glei Alpine Meadow Bog Half Bog Planosols Ground-Water Podzol Ground-Water Laterite

Distinctions among the great soil groups are not always clearly defined.

Some of the common gleyed soils in Alberta have been classified as Meadow, Half Bog, Bog, and Depression or Slough Podzols. (16, 38).

At the 1955 National Soil Survey Conference in Saskatoon (54) Stobbe outlined a classification system for the soils of Canada. Poorly drained soils fit into the system as follows:

Category VI	Category V
6. Gleizolic soils Soils with peaty (less than 12") or mineral surface high in O.M. or both and dull colored subsoils (with chroma of 1 or less or not higher than P.M.) and/or with brighter colored prominent mottles. Poorly drained soils developed under various climatic and vegetative conditions in the presence of high or strongly fluctuating water table.	1. Meadow 2. Dark Grey Gleizolic 3. Solonchack 4. Peaty Glei 5. Podzolic Glei 6. Grey Wooded Glei.

Another class in category VI, Organic soils, in-

cludes profiles with gleyed subsoils.

Joffe (31) lists profile descriptions and chemical analysis data of gleyed soils investigated by Zavalishin and other Russian workers. They found that some of the main chemical features of gleyed soils are:

1. pH usually increases with depth reaching approximately seven in the glei horizon.
2. The ferrous iron content of the glei horizon is high but there is little ferrous iron in the soil solution.
3. The exchange complex is generally base saturated. There is an increased proportion of magnesium in the glei horizon.
4. Total analysis of different horizons usually show no sharp fluctuations.
5. There may be secondary deposits of hydrated ferric oxides, MnO_2, $CaSO_4$, $CaCO_3$, and clay.
6. Organic matter content of the glei horizon is low but the soluble humus content is high.

Russell (46) mentions that alternating oxidizing and reducing conditions in a horizon results in the accumulation of iron and manganese in that horizon.

Joffe (31) states that Russian pedologists explained the grey to blue-grey color of gleyed soil as being due to ferrous iron compounds such as vivianite, $Fe_3(PO_4)_2 \cdot 8\ H_2O$ which is white when unoxidized and bluish when slightly oxidized. Iron mottling was thought to be due to localized aeration and oxidation of ferrous iron.

Van der Spek (59) explains the light grey color of gleyed soils as being due to ferrous bicarbonate and blackish colors as being due to sulfides.

The low productivity of gleyed soils has been studied. Robinson (45) concludes that soils subjected to periodic submergence may be unproductive because of the presence of toxic substances such as ferrous iron or sulfide, loss of nutrients or low oxygen supply.

Heathcote (28) found that gleying resulted in marked deterioration in fertility of some Yorkshire soils. Gleyed soils required more lime and phosphorus, and slightly more potassium than associated normal soils.

Albrecht (1) was among the first to report on the role of microorganisms in gleying. His work indicated that gleization is active when three conditions are satisfied:

1. Ample calcium for bacterial nutrition.
2. Standing water to cut off the oxygen supply.
3. Organic matter as an energy source for the bacteria.

Ignatieff (30) studied the ferrous iron content of Grey Wooded, Black, and Bog soils in Alberta. Some of his conclusions were:

1. Ferrous iron enters into cation exchange reactions. There is little ferrous iron in the soil solution.
2. Microorganisms are involved in the production of ferrous iron.
3. Ferrous iron is produced rapidly in saturated soils but it moves downward slowly.

4. Grey Wooded and Black soils to a depth of two feet usually contain no more than two to three p.p.m. of ferrous iron. Peats may contain 200 to 600 p.p.m.

Ignatieff's method of extracting ferrous iron has been questioned by Bloomfield (6). Results reported by Schnitzer and De Long (49) indicate the dipyridyl method of determining ferrous iron is not accurate if organic matter is present. This was the method used by Ignatieff.

Since 1949, Bloomfield (5, 6) has conducted extensive laboratory studies on the mechanism of gleization. His work has thrown new light on the process. Some of his major conclusions are:

1. Water extracts of organic materials can bring about the solution and reduction of iron. The grey color of gleyed soil is due to the removal of coatings of ferric iron compounds.
2. Microorganisms usually contribute greatly to the gleying process but gleying can occur due to the action of plant extracts without the presence of microorganisms. This is of significance in areas where maximum leaching occurs when the soil is too cold for optimum bacterial conditions.
3. Iron can remain in solution at high pH's as ferrous-organic complexes.
4. Ferrous iron formed in the gleying process is immobilized by adsorption on ferric oxide surfaces lower in the profile. When conditions become aerobic, the adsorbed ferrous iron is oxidized to ferric oxide. This gives a

fresh surface for the adsorption of more ferrous iron. Such a mechanism could explain the accumulation of iron in mottles or in definite horizons.

Bloomfield (7) also studied the iron content of a mottled and an unmottled gley soil. In the unmottled soil, total iron and "free" iron (acid ammonium oxalate extractable) increased with depth. In the mottled soil, the brown mottles were greatly enriched with iron and much iron had been removed from the grey material. The "free" iron content of the brown mottles was 8.9% while that of the grey material was 0.6%. Bloomfield suggests that iron mottling isn't a part of the gley process but a secondary opposing effect governed by aeration resulting from cracks and root channels.

B. Studies of Soil Redox Potentials

1. Meaning and significance of redox potentials

Oxidation involves a loss of electrons ($Fe^{++} - e \rightarrow Fe^{+++}$). Reduction involves a gain of electrons ($Fe^{+++} + e \rightarrow Fe^{++}$). The oxidation of one substance involves the reduction of another.

The oxidation potential of a substance is a measure, in terms of electrical potential, of its affinity for electrons. Oxidizing substances have a strong affinity for electrons. Reducing substances give off electrons readily. Thus if inert electrodes in an oxidizing and a reducing substance are connected with a wire to carry electrons and a salt

bridge to allow for ion transfer, an electric current or stream of electrons will flow from the reducing to the oxidizing substance. During the process, the reducing substance is oxidized and the oxidizing substance is reduced. Electron transfer continues until the pressure of electrons in the two substances is the same.

The above process may be illustrated by describing a simple oxidation-reduction (redox) cell. Suppose that a solution in beaker A contains Fe^{++} and Fe^{+++} in a 10:1 ratio. Beaker B contains Fe^{++} and Fe^{+++} in a 1:10 ratio. A platinum electrode is placed in each beaker. The electrodes are joined by a copper wire which is connected with a sensitive voltmeter. One arm of a U tube containing a salt solution is placed in each beaker. Since beaker A contains a large proportion of reduced substance, electrons flow through the wire from A to B. Anions migrate through the salt bridge from B to A to maintain the cation-anion equilibrium in the solutions. The voltmeter would roughly indicate the difference in potential of the solutions in the beakers.

In practice, a potentiometer is used to measure redox potentials. This instrument exactly balances the e.m.f. of the cell being measured with an opposing e.m.f. the magnitude of which may be read. In this way, no electron transfer takes place and the cell maintains a constant e.m.f.

The redox potential of a solution may be determined as follows:

1. Insert a platinum electrode and a saturated calomel electrode into the solution.
2. Connect the leads from the electrodes to a potentiometer.
3. Adjust the potentiometer to balance the e.m.f. of the cell and read the e.m.f. indicated on the potentiometer.
4. Calculate e.m.f. of solution. E.m.f. of cell is x . E.m.f. of saturated calomel electrode is +244 mv. (as compared with the standard hydrogen electrode with e.m.f. = 0). If the platinum electrode was more positive than the calomel (as indicated by the way the electrodes were connected to the potentiometer when it balanced the cell e.m.f.) then e.m.f. of the solution was (x + 244). If the platinum electrode was more negative than the calomel, then e.m.f. of solution was (244 - x).

It should be noted that the redox potential of a substance gives no idea of its oxidizing or reducing capacity just as pH give no measure of total acidity.

Oxidation-reduction processes occur in soils. The inorganic soil fraction is usually largely in the oxidized state. According to Bear (4), elements subject to reduction are iron, manganese, titanium, copper, and chlorine. Organic soil material is largely in a reduced state. Components subject to oxidation are carbon, nitrogen, sulfur, phosphorus. In the gaseous phase of soil, oxygen is an important oxidizing substance. Soil organic matter is largely oxidized at the soil surface where there is a good supply of oxygen and the

catalytic influence of iron, manganese and copper (4).

The redox potential of soil may be significant in relation to several aspects of soil science, particularly genesis and fertility. Elements such as iron and manganese are more soluble in the reduced state. Thus, in a soil with a low redox potential (E_h), more movement of iron and manganese seems probable. Plants usually require the oxidized forms of nutrients. Reduced forms are often toxic. Thus low E_h may indicate toxicity.

2. Soil redox potential measurements

Before 1920, when Gillespie (26) made the first measurements of soil redox potentials, chemical tests were sometimes used to determine the oxidizing or reducing capacity of soil. Gillespie reasoned that since the measurement of the intensity factor of acidity, pH, had recently proved useful, the same might hold for oxidation.

He measured redox potentials of aerated and waterlogged soils under natural conditions in the field and under artificial laboratory conditions. His findings were:

1. Soils are poorly poised so frequently duplicate E_h readings vary considerably.
2. Presence of oxygen greatly increases E_h.
3. Adding dextrose to soil decreases E_h and retards growth of rice seedlings.

4. pH should be measured with Eh. This follows from the Nernst equation, $E = Eo + \frac{RT}{nF} \ln \frac{(ox)}{(red)}$

Increase in (H^+) increases $\ln \frac{(ox)}{(red)}$ and thus increases E.

From his studies, Gillespie concluded that the low productivity of wet soils is due to reducing conditions more than to acidity.

Between 1930 and 1940, many papers were published on the Eh of soils. Results of workers were frequently contradictory, probably because the desirability of measuring redox potentials of soil in situ was not generally accepted. Some of the opinions and findings during this period are listed:

1. Bradfield et al (17) found Eh a good criterion for evaluating the suitability of soil for orchard purposes. Low Eh during April and May indicated undesirable soil.
2. Buehrer et al (19) found that adding organic matter to wet soil caused a drop in Eh. Burrows and Cordon (20) found that adding protein raised Eh; carbohydrate and little effect.
3. Burrows and Cordon (20) stated that exclusion of oxygen had little effect on Eh. Willis (63) and Buehrer et al (19) showed that oxygen is a very important factor in determining Eh. Puddling lowered, and aerating markedly increased, Eh.
4. Methods of preparing the soil sample for Eh measurement differed greatly. Brown (18) discussed dozens of ways of preparing the sample. These include in situ measure-

ments, addition of acid, and bubbling nitrogen through the wet soil. In situ measurements were not often used as they are less convenient and good duplication is harder to achieve.

5. Volk (60, 61) attempted to find relationships between Eh, soil characteristics, and plant growth. He found little variation in the Eh of Alabama soils and no direct relationships between Eh and plant growth. Sand cultures at Eh from 550 to 300 mv. appeared equally suitable for plant growth.
6. Workers used different methods of preparing and cleaning electrodes. This, and the variation in sample preparation, probably led to the contradictory findings.

Since 1945, the method of measuring soil Eh has been reasonably well standardized apparently due to the work of Quispel in Holland and Starkey and Wight in the United States.

Starkey and Wight (52) found that soil Eh was the most reliable index of probable corrosion of iron gas pipes. They carried out a thorough study of techniques of measuring Eh. The most significant results came from in situ measurements of Eh of moist soil. They developed a probe containing two bright platinum electrodes, a calomel and a glass electrode. The probe was inserted into a previously made hole and Eh and pH were measured with a Beckman pH meter.

They found: (1) E_h less than 100 indicates very corrosive soil containing sulfide.
(2) E_h greater than 400 indicates non-corrosive soil.
(3) Organic matter had little effect on E_h of aerobic soils, but it markedly lowered E_h of waterlogged soils.
(4) Potentiometric titrations showed much greater amounts of reduced material in waterlogged soil.

Quispel (42) measured the change in E_h over a period of several months of inundated soils which were drained. Results were very variable but there was a large increase in E_h with time after draining. Just after draining, E_h averaged - 240 mv.; two weeks later, -25 mv.; two months after draining, +98 mv. Quispel stated that E_h measurements would be useful in predicting when a drained soil would be capable of producing certain crops.

Quispel showed that in strongly reduced soils, E_h is largely determined by oxygen and sulfide. Bacteria and reducing organic substances have an influence on E_h of partially aerated soil. E_h of well aerated soil is largely determined by oxygen.

Quispel's method of measuring soil E_h was similar to that of Starkey and Wight. However, he used platinized platinum electrodes as they gave a more stable potential.

Pierce (40) found good correlation between forest types and the electro-chemical properties of ground water. There was a distinct negative correlation between

E_h and dissolved oxygen in ground water.

Wilde (62) found similar results in a study of ground water in organic soils. E_h of the ground water below moss peat averaged -250 mv.; below sedge peat, +50 mv.

McKenzie and Erickson (36) used E_h measurements in a soil genesis study. In situ measurements of E_h of two Podzols and a Humic Glei were taken from spring to fall. E_h of the sandy Podzol was +600 mv. by the first week of May. E_h of the loam Podzol had risen to 600 by the third week of May. Usually surface readings were lower than those taken deeper in the profile. E_h of the Humic Glei increased from -600 mv. in May to +600 mv. in July. The surface E_h was highest.

In a laboratory phase of this study, McKenzie and Erickson (36) prepared cylinders of sand with mixed A_o and A_1 on top and platinum electrodes inserted at four depths. The cylinders of sand were leached with water. E_h at 3" from the top was significantly lowest. After six weeks of leaching, the cylinders were opened and samples were taken at different depths. These were extracted with acidic NH_4Ac and ferric and ferrous iron were determined in the extract. The greatest percentage of ferrous iron was extracted from the sample taken at a depth of 3".

The ratio of ferrous iron to total iron was 50% in the extract from the 3" sample and 30% to 10% from extracts of samples taken lower in the columns.

McKenzie and Erickson concluded that E_h measurements might be useful in the study of soil genesis.

In a recent study, Copeland (23) measured the effects of moisture and compaction on soil redox potentials. E_h readings were generally high - over 700 mv., and similar for all treatments. Saturation and compaction resulted in somewhat lowered potentials. Copeland suggested that the small differences were due to large amounts of hydrated ferric oxides and little active organic matter in the Hagerstown soil used. Possibly differences would have been larger if potentials had been measured in situ rather than in 1:1 soil suspensions. Copeland found that although variations in redox potentials were small, higher amounts of Fe^{++} and Mn^{++} were correlated with lower potentials.

C. Laboratory Studies of Soil Genesis

Since a part of this study involved an attempt to acquire information on soil genesis from columns of soil set up under artificial conditions, some of the relevant literature on this type of study will be reviewed.

Although the experimental approach to soil genesis study has been widely used only in recent years, its original application goes back at least to the time of the early Russian work reported by Glinka (27). He records that Kostytscheff leached six inches of A horizon material from a Chernozem in a glass tube with water and found that leaching can effect the degradation of a Chernozem.

Henin and Betremieux (29) suggest that in studying soil forming processes, pedology must pass from the observational to the experimental stage. Their experiments involved the leaching of soil material in glass tubes with water and various solutions. Their findings may be summarized as follows:

1. When soil was leached with distilled water, clay accumulated at the base of the column or passed out in the leachate.
2. When a lime layer was placed in the soil column, clay accumulated above the lime.
3. If the soil exchange complex was alkali saturated, the layer of clay accumulation became impervious.
4. Leaching the soil with a glucose - $(NH_4)_2\ SO_4$ solution caused gleying. This leachate was reddish due to the presence of iron.
5. When a mixture of 90% soil and 10% $CaCO_3$ was leached with the glucose solution, gleying occurred and there was iron in the leachate. The pH of the leachate was greater than 7. They concluded: (a) Iron solution and movement was due not to acidic reaction, but to redox phenomena. (b) Iron must have moved as a complex or it would have precipitated at the prevailing pH.
6. When the soil was leached with extracts of various organic substances, gleying and iron movement occurred in proportion to the degree of breakdown of the organic material used.
7. Under intense reducing conditions, the soil and the leachate became blackened due to the presence of sulfide.

8. Gleying and iron movement were increased greatly by the addition of $(NH_4)_2SO_4$ as well as glucose to the leaching solution. When NH_4Cl, NH_4NO_3 or $(NH_4)_3PO_4$ were substituted for $(NH_4)_2SO_4$ in the leaching solution, very little gleying occurred. Henin and Betremieux reasoned that $SO_4^=$ probably favored the growth of microorganisms which played an important part in the gleying process.

9. Most of the iron removed from the leached soil came from crystalline iron hydroxides or from iron bearing compounds in the colloidal state. Some iron was removed from primary minerals.

Several of these results have a direct application to the explanation of soil profile development under field conditions. For instance, the accumulation of clay above the lime layer is typical of Grey Wooded profiles. Podzol profiles which characteristically do not have a distinct horizon of clay accumulation usually form on non-calcareous materials.

For eight years, Bloomfield has been conducting laboratory studies of the processes of gleization and podzolization. His work on gleization has already been discussed. The work on podzolization is a good example of experimental pedology. It began with a series of measurements of the mobilization of Fe and Al from the oxides of these elements by aqueous extracts of the leaves and bark of various trees (8,9,10,11,12).

The experiments were carried out under several conditions, aerobic, anaerobic, and with toluene added to prevent bacterial action. Results indicate:

1. Tree leaf extracts cause non-biological solution of Fe and Al oxides.
2. The dissolved iron is partially in the ferrous state, probably as a ferrous-organic complex.
3. An appreciable amount of iron remains in solution even at pH greater than 7. Iron in solution decreases with increased pH. Generally conifer leaf extracts have higher iron and aluminum mobilizing power than extracts of broadleaved tree species. Aspen leaf extracts have relatively high mobilizing power at pH greater than 7 (12). This suggests that aspen should be a fairly strong Podzol former. High calcium and magnesium in aspen leaf extracts suggests an explanation for the high base saturation of Grey Wooded soils.

Bloomfield's study (13) of the reasons for reprecipitation of iron in Podzol B horizons led to evidence that iron brought into solution by active factors in leaves is adsorbed on ferric oxide surfaces and there reprecipitated. Adsorption, on ferric oxide surfaces, of iron mobilized by the extracts of various leaves varied inversely as the podzolizing power of the

species involved. Bloomfield thought that the podzolizing properties of a tree species may depend on:

1. The relationship between the iron solution and iron adsorption properties of leachates which have passed through its residues.
2. The effect of these leachates on clay transportation.

Ferrous compounds in leaf leachates are strongly adsorbed on kaolin, but not on silica. Thus removal of clay from an A_2 horizon decreases the probability of adsorption and subsequent oxidation of ferrous-organic complexes in that layer. Conversely, build up of clay in a B horizon increases the probability of adsorption of ferrous-organic compounds. If adsorption facilitates oxidation, then oxidation of the ferrous iron would occur even under partially aerobic conditions. The fresh ferric oxide formed would act as another favorable surface for the adsorption of ferrous iron. Such a mechanism could account for the sesquioxide rich B of a Podzol.

This reasoning led to a study of the deflocculating effect on clays of tree leaf leachates (15). Results indicated that leaf leachates have a deflocculating effect on kaolin and that the magnitude of this effect varies with tree species.

Work with exchange resins and leaf extracts indicated that the constituents of the extracts which are responsible for sesquioxide movement are likely organic acids and reducing substances (14).

Bloomfield's study of podzolization leaves many questions unanswered but his method of attacking the problem led to the development of some ideas regarding:

1. The reasons for sesquioxide movement.
2. The reasons for sesquioxide precipitation.
3. The reasons for the variations in podzolizing abilities of different species.
4. The nature of the sesquioxide mobilizing constituents of leaf extracts.

Work by De Long and his associates (22,24,33, 34,48,49,50) parallels that of Bloomfield in some respects. However, De Long has made a greater effort to approximate natural conditions. For instance, leaf leachates were caught in pans placed below the A_o horizon in the forest. Also the leachates have been tested on soil, not just on iron and aluminum oxides.

De Long's investigation began with the assumption that substances leached from leaf litter by precipitation are of importance in the process of podzolization. Thus it was necessary to s tudy:

1. Leaves - quantity falling, rate of decomposition, and chemical composition at various stages.
2. Leaf leachates - chemical nature.
3. Interaction of leaf leachates with soil.

Much basic information has been reported from these studies. In general, De Long's conclusions regarding the mobilization of sesquioxides by leaf leachates are similar to those of Bloomfield. However, Schnitzer and De Long (50) presented data to indicate that laboratory prepared leaf extracts, as used by Bloomfield, differ markedly from natural leaf leachates in their capacity for mobilizong iron.

In a study of the capacities of leaf leachates to hold iron in solution, De Long and Schnitzer (24) found that the amount of iron held increased with pH. Also, when NaOH was used to increase the pH, more iron was held in solution than when $Ca(OH)_2$ was used. These results suggest that iron should move most readily in sodium dominated soils. Another part of this study indicated that the ferric oxide-organic matter ratio is very important in determining the degree of solution or reprecipitation of iron.

Treatment of soil with poplar, beech, and maple leaf extracts showed that iron and aluminum are

mobilized in measurable quantities by these extracts, (24).

Stobbe (53) shook samples of a calcareous and a non-calcareous soil with maple leaf leachate and periodically determined Ca, Mg, Al, and Fe. A striking result was that a far greater percentage of the total iron present was removed from the calcareous than from the non-calcareous soil. Stobbe reasoned that the removal of $CaCO_3$ would disrupt the soil fabric and expose fresh surfaces to the action of the leachate. In non-calcareous soils such disruption would not occur.

Thorp and associates (56) carried out a laboratory study on the role of leaching in soil genesis. Soil contained in glass tubes was leached with various organic acids - such as oxalic and tannic, and water soluble material from leaves. The leachate was analyzed periodically for Ca, Mg, Fe, and Mn. Results were as follows:

1. Leaching with organic acids for four months produced the beginning of a profile - a bleached A_2 and a B of stronger color.
2. Extracts from leaves of different tree species varied in effectiveness as initiators of profile development.

3. Ca, Mg, Fe, Mn, and soluble silicates were detected in the leachates.

4. It appeared that fine clay was removed from the upper part of the columns and partially redeposited farther down.

For several years, Atkinson, Wright and associates have been investigating the role of chelation in soil development (3,64). They began with the hypothesis that if chelation is involved in pedogenesis, then leaching soil material with a chelating agent should bring about changes similar to those which occur naturally. They leached a calcareous sandy soil in glass tubes with distilled water and a dilute solution of disodium EDTA. Tubes leached with distilled water developed a slight browning at the surface due to an increase in iron oxides. Those leached with EDTA developed a Podzol type profile. Iron and aluminum were removed from the A_2 and partially redeposited in the B horizon.

Further studies of a similar nature (3) indicated the following trends in development of soil leached with EDTA:

1. EDTA leaching first decomposed carbonates.

2. Ca/Mg ratio in the leachate decreased with time.

3. Fe and Al mobilization increased as pH and Ca and Mg decreased.

Lower in the profile, where the pH was higher and more Ca and Mg were present, Fe, and Al were precipitated as hydrated oxides.

Folks and Riecken (25) used the laboratory approach to study the reason for the occurrence of clay-iron bands in Iowa soils of loamy sand texture. They leached loamy fine sand contained in a four foot glass tube with 0.01 N oxalic acid. After a week of leaching at the rate of 1.5 c.c. per min., there was visible banding at a depth of between 30 and 38 inches. They considered that periodic precipitation of iron oxide best explained the band formation. It seemed probable that after a critical amount of iron was complexed and moved, environmental conditions were such that the complex was broken and iron was precipitated. Further studies by these authors lent support to this concept. Folks and Riecken cite results of studies of a similar nature by other workers. Some, but not all, of the results support their conclusions.

Results of these trials of experimental pedology illustrate that the laboratory approach to the study of processes of soil formation is a promising one. The need for a greater understanding of the mechanisms

involved in the development of the soil profile is indicated in a paper by Carter and Pendleton (21). They propose arguments, based on reports in the literature, intended to show that laterization is an advanced stage of Podzol development. According to them only one basic soil forming process is active in humid regions whether temperate or tropical. These authors suggest that this has been overlooked by soil scientists because pedology began with description and classification based upon morphology. Study of processes is in its infancy.

Whether or not the arguments of Carter and Pendleton are correct, the inability of pedologists to definitely refute them illustrates the need for objective studies of soil forming processes.

III. NATURE OF STUDY

This project was undertaken to determine something of the characteristics and development of some of Alberta's Slough Podzols (gleyed soils with a strongly eluviated horizon). There are two parts to the study:

1. An investigation of morphological and chemical characteristics of Slough Podzols and adjacent well drained soils.
2. A laboratory study of soil material maintained under different drainage conditions intended to simulate some conditions involved in the genesis of Slough Podzols.

The field study involved observing and sampling Slough Podzol profiles over a relatively large area of Alberta. One or two related well drained profiles were sampled at each site for purposes of comparison. Analyses designed to determine the characteristics of Slough Podzols and their differences from adjacent zonal soils were carried out on the field samples.

For the laboratory phase of the project, soil contained in rectangular plastic columns was studied to determine:

1. The effect of various moisture conditions and surface organic matter on soil E_h.

2. The effect of various moisture conditions and surface organic matter on the composition of the leachate from the soil columns.

3. The morphological differences produced by subjecting soil material to various drainage conditions.

An attempt is made to use some of the results of the laboratory study to partially explain certain features of the profiles sampled in the field.

IV. MATERIALS AND METHODS

A. Soil Profile Descriptions

Terminology used is that outlined by the Third Conference of the Canada Soil Survey Committee (54). All colors given are dry colors.

SITE I

This site located in NW 10-47-20-4, near Camrose, comprised a depression and the adjacent slope in a gently undulating till plain.

Profile I

This profile was a Slough Podzol sampled in the depression. Vegetation consisted of aspen, willow and sparse grass cover. The profile formed on a shallow lacustrine deposit over glacial till at 24".

Horizon	Depth	Description
O	3 - 0"	partially decomposed leaves.
Ahe	0 - 1"	dark grey (10YR-4/1) weak platy, friable, silt loam.
Aeg	1 - 3½"	light grey (10YR-7/1) moderate platy, friable, iron mottled, silt loam.
A-Bg	3½-6½"	pale brown (10YR-6/3) platy to coarse granular, slightly hard, strongly iron stained, silt loam.
Btg_1	6½-16"	grey brown (10YR-5/2) massive to coarse blocky, very hard, iron mottled, clay loam.
Btg_2	16-24"	light brownish grey (10YR-6/2) massive, very hard, iron mottled, clay loam.
Dg	24"+	clay loam till.

Profile 2

This moderately well drained degrading Black soil was sampled ten yards up a 2% slope from profile 1. Vegetation and parent material are the same as for profile 1.

Horizon	Depth	Description
O	3 - 0"	partially decomposed leaves.
Ah	0 - 4"	very dark (10YR-3/2) very weak platy, friable, silt loam.
Ae	4 - 8"	light brownish grey (10YR-6/2) moderate platy, slightly hard, silt loam.

Horizon	Depth	Description
Bt	8 - 13"	pale brown (10YR-6/3) weak prismatic breaking to medium subangular blocky, hard, silty clay loam.
Btg	13 - 24"	pale brown (10YR-6/3) massive to coarse blocky, very hard, iron mottled, clay loam.
D	24"+	clay loam till.

Profile 3

This profile was taken 20 yards up a 1% slope from profile 2. The soil was a well drained, slightly degraded Black. Native cover was grass.

Horizon	Depth	Description
Ah_1	0 - 12"	very dark grey (10YR-3/1) fine granular, friable, silt loam.
Ah_2	12 - 17"	dark grey (10YR-4/1) fine blocky, slightly hard, silt loam.
Ae - B	17 - 24"	light brownish grey (10YR-6/2) medium subangular blocky, hard, silt loam.
D	24"+	pale brown (10YR-6/3) massive, very hard, slightly iron mottled, clay loam till.

SITE II

This site, located in SW 7-50-1-4, near Lloydminster, comprised a depression and the adjacent ridge in an undulating area at the edge of a segment of the Viking Moraine.

Profile 1

This profile was a Slough Podzol sampled in a depression at the base of a 5% slope. Vegetative cover consisted mainly of aspen and willow. The profile apparently formed on water-sorted till. Alluvial material occurred at a depth of 32".

Horizon	Depth	Description
O	3 - 0"	leaves, partially decomposed.
Ahe	0 - 5"	dark grey (10YR-4/1) weak platy, friable, silt loam.
Aeg	5 - 12"	light grey (10YR-7/2) platy, slightly hard, somewhat iron mottled at 5-8", intensely mottled at 10-12", silt loam.
Btg	12 - 23"	light brownish grey (10YR-6/2) massive, very hard, strongly iron mottled, silty clay loam.
Bg	23 - 32"	pale brown (10YR-6/3) massive, hard, strongly mottled, silt loam.
Dg	32"+	light yellowish brown (2.5Y-6/4) massive, friable, intensely iron stained, silt loam.

Profile 2

Profile 2 was a strongly developed degrading Black soil occurring on a 5% slope above profile 1. The native cover was dominantly aspen.

Horizon	Depth	Description
O	4 - 0"	undecomposed and partially decomposed leaves.
Ah	0 - 5"	dark greyish brown (10YR-4/2) weak platy to fine granular, friable, loam.
Ae	5 - 10"	light grey (10YR-7/2) weak platy, friable, sandy loam.

Horizon	Depth	Description
Bt_1	10 - 18"	brown (10YR-5/3) moderate, fine blocky, hard, clay loam.
Bt_2	18 - 31"	light yellowish brown (10YR-6/4) prismatic breaking to medium blocky, very hard, clay loam.
Bca	31 - 46"	light brownish grey (10YR-6/2) massive to angular blocky, very hard, clay loam.
C	46"+	light brownish grey (10YR-6/2) massive, very hard, clay loam till.

Profile 3

This profile, a thin Black soil, was sampled at the crest of a grass covered ridge above profile 2. The parent material was calcareous till.

Horizon	Depth	Description
Ah	0 - 4"	very dark grey (10YR-3/1) fine granular, friable, loam.
B_1	4 - 9"	dark greyish brown (10YR-4/2) prismatic breaking to medium subangular blocky, slightly hard, clay loam.
B_2	9 - 16"	brown (10YR-5/3) prismatic breaking to strong subangular blocky, hard clay loam.
Bca	16 - 34"	light brownish grey (10YR-6/2) massive, slightly hard, clay loam.
C	34"+	light brownish grey (10YR-6/2) massive, hard, clay loam till.

SITE III

Site III, in SW 15-50-1-4, was similar to Site II.

Profile 1

This was a Slough Podzol profile sampled in an aspen covered depression. It formed on water-sorted till overlying alluvial sandy loam.

Horizon	Depth	Description
O	3 - 0"	partially decomposed leaves.
Ahe	0 - 1"	dark grey (10YR-4/1) weak platy, friable, silt loam.
Aeg	1 - 6"	light grey (10YR-7/2) platy, friable, iron mottled, sandy loam.
Btg	6 - 18"	pale brown (10YR-6/3) massive to fine subangular blocky, hard, iron mottled, clay loam.
Dg	18"+	light yellowish brown (10YR-6/4) stratified, alluvial sandy loam, intensely iron stained.

SITE IV

Site IV was a shallow depression and the adjacent slope in SW 6-47-19-4, near Camrose. The landscape was a gently undulating till plain.

Profile 1

Profile 1 was a Slough Podzol sampled in the wooded (aspen and willow) depression.

Horizon	Depth	Description
O	3 - 0"	partly decomposed leaves.
Ahe	0 - 3"	grey (10YR-5/1) soft, weak platy, silt loam.
Aeg	3 - 8"	white (10YR-8/1) soft, platy, iron mottled (10YR-6/6) sandy loam.

Btg_1	8 - 14"	greyish brown (10YR-5/2) prismatic breaking to medium subangular blocky, hard, iron mottled, (10YR-5/8) clay loam.
Btg_2	14 - 24"	light brownish grey (10YR-6/2) massive to coarse subangular blocky, very hard, iron mottled (10YR-6/6), silty clay loam.
Btg_3	24 - 44"	light brownish grey (10YR-6/2) massive to coarse blocky, iron mottled (10YR-6/5), clay loam.
Cg	44"+	light grey to grey (10YR-6/1) massive, hard, somewhat iron mottled till.

Profile 2

This was a black Solodized Solonetz profile. It was sampled 20 yards up a 2% slope from profile 1. Native vegetation and parent material were the same as those for profile 1.

Horizon	Depth	Description
O	3 - 0"	partly decomposed leaves and roots.
Ah	0 - 10"	dark to very dark grey (10YR-3.5/1) granular, slightly hard, clay loam.
ABe	10 - 11"	grey (10YR-5/1) granular to fine subangular blocky, silt loam.
Bt_1	11 - 24"	greyish brown (10YR-5/2) columnar breaking to medium subangular blocky, hard, clay loam.
Bt_2	24 - 42"	greyish brown (10YR-5/2) weak prismatic breaking to medium subangular blocky, hard, slightly mottled, clay loam.
C	42"+	greyish brown (10YR-5/2) slightly iron mottled till, clay loam.

Figure 1. shows the Slough Podzol from Site IV and a Black Solodized Solonetz profile similar to the one from Site IV.

black Solodized Solonetz

Slough Podzol

Figure 1. Profiles similar to those from site IV.

SITE V

Site V was in NW 7-46-18-4, near Camrose. The landscape was the same as that described for Site IV.

Profile 1

Profile 1 was a Slough Podzol. It was sampled in a shallow depression. Native cover was aspen and grass.

Horizon	Depth	Description
O	$2\frac{1}{2}$ - 0"	partly decomposed leaves.
Ahe	0 - $1\frac{1}{2}$"	grey (10YR-5/1) platy to granular, friable, loam.
Aeg	$1\frac{1}{2}$ - $7\frac{1}{2}$"	light grey (10YR-7/2) platy, somewhat iron mottled (10YR-6/5) friable, sandy loam.
A - Bg	$7\frac{1}{2}$ - 13"	light brownish grey (10YR-6/2) platy to fine subangular blocky, strongly mottled (10YR-6/5) sandy clay loam.
Btg_1	13 - 22"	greyish brown (10YR-5/2) iron mottled, fine subangular blocky, hard, clay loam.
Btg_2	22 - 34"	greyish brown (10YR-5/2) iron mottled, prismatic to medium blocky, hard, clay loam.
Cg	34"+	light brownish grey (10YR-6/2) slightly mottled, clay loam till.

Profile 2

This profile was a Black soil sampled in a moderately well drained position near profile 1. Native cover was grass.

Horizon	Depth	Description
Ah	0 - 11"	very dark grey (10YR-3/1) granular, friable, clay loam.
B	11 - 18"	dark greyish brown (10YR-4/2) fine subangular blocky, slightly hard, silty clay.
Bca	18 - 30"	greyish brown (10YR-5/2) coarse granular, slightly hard, silty clay.
Bsa	30 - 46"	light brownish grey (10YR-6/2) massive to fine blocky, slightly hard, silty clay loam with salt crystals.
Cg	46"+	pale brown (10YR-6/2) massive, silty clay textured till with some iron mottling.

Figure 2 shows the Slough Podzol from Site V and a Black soil similar to the one sampled at Site V.

SITE VI

Site VI, in SW 17-79-10-6, near Gordondale, was a depression and the adjacent slope in a gently undulating lacustro-till area.

Profile 1

This soil, classified as the Snipe series, was sampled in a depression.

Horizon	Depth	Description
O	4 - 0"	partly decomposed leaves and roots.
Ah	0 - 1½"	very dark greyish brown (10YR-3/2) friable, silty clay.
Aeg	1½ - 7"	greyish brown (2.5Y-5/2) platy, strongly iron stained (2.5Y-5/6), silt loam.

Black Slough Ponded

Figure 2. Profiles similar to those from site V.

Horizon	Depth	Description
Bg_1	7 - 10"	grey (10YR-5/1) medium blocky, iron mottled (10YR-5/6) hard, clay.
Bg_2	10 - 22"	dark greyish brown (10YR-4/2) medium blocky, very hard, iron mottled, clay.
Bg_3	22 - 28"	dark to very dark greyish brown (10YR-3.5/2) medium blocky, very hard, clay.
Cgca	28"+	very dark greyish brown (10YR-3/2) massive, hard, clay.

Profile 2

Profile 2 was a Grey Wooded soil of the Donnelly series, sampled at the top of the slope above profile 1. Native cover was dominantly aspen.

Horizon	Depth	Description
Ah	0 - 1"	very dark greyish brown (10YR-3/2) fine granular, soft, silt loam.
Ae	1 - 4"	pale brown (10YR-6/3) platy, soft, silt loam.
A - Be	4 - 7"	brown (10YR-5/3) fine blocky, slightly hard, clay.
Bt_1	7 - 20"	dark brown to brown (10YR-4/3) columnar to medium blocky, very hard, clay.
Bt_2	20 - 25"	dark grey (10YR-4/1) medium blocky, very hard, clay.
Bca	25 - 30"	dark grey (10YR-4/1) medium blocky, very hard, clay.
C	30"+	dark grey (10YR-4/1) massive, very hard, clay.

Figure 3 shows profiles of Snipe and Donnelly similar to those which were sampled at Site VI by Mr. J. D. Lindsay.

Grey Wooded (Donnelly)

Slough Podzol (Snipe)

Figure 3. Profiles similar to those from site VI.

SITE VII

This site, located in NW 15-28-5-4, near Oyen, was a depression in a gently rolling moraine area.

Profile 1

Profile 1, a Slough Podzol was sampled in the depression. Vegetation consisted of aspen and grass. Parent material was inwash from the adjacent 5% slopes.

Horizon	Depth	Description
O	1 - 0"	partly decomposed leaves and grass.
Ah	0 - 1.5"	dark grey (10YR-4/1) fine granular, friable, silt loam.
Ahe	1.5 - 6"	greyish brown (10YR-5/2) weak platy, friable, sandy loam.
Aeg	6 - 17"	pale brown (10YR-6/3) with prominent mottles (10YR-6/6), platy, soft, sandy loam.
Btg	17 - 36"	greyish brown (10YR-5/2) coarse prismatic to medium subangular blocky, very hard, somewhat mottled, clay loam.
B - Cg	36 - 50"	light brownish grey (10YR-6/2) massive to coarse blocky, clay loam, slightly mottled.
C	50"+	light brownish grey (10YR-6/2) massive, fairly hard, slightly mottled, clay loam.

SITE VIII

Site VIII was in SW 1-55-24-4, near Namao. It comprised a shallow depression and the adjacent very gentle slope in an almost level lacustrine area.

Profile 1

This profile was a Slough Podzol sampled in the depression. Native cover was aspen, willow, and grass.

Horizon	Depth	Description
O	1 - 0"	partly decomposed leaves and grass.
Aeg	0 - 7"	light grey to grey (10YR-6/1) platy, iron mottled, silt loam.
Btg_1	7 - 20"	greyish brown (10YR-5/2) coarse prismatic, mottled, very hard, clay.
Btg_2	20 - 40"	light brownish grey (10YR-6/2) massive, very hard, clay.
Cg	40"+	light brownish grey (10YR-6/2) massive, hard clay.

Profile 2

This profile, classified as Wetaskiwin clay loam, was a black Solodized Solonetz soil. It was sampled 150 yards up a ½% slope from profile 1.

Horizon	Depth	Description
Ah	0 - 10"	very dark grey (10YR-3/1) fine granular, friable, clay loam.
Ae	10 - 10½"	light grey to grey (10YR-6/1) platy, silt loam.
Btna	10½ - 18"	dark grey (10YR-4/1) strong columnar breaking to medium subangular blocky, very hard, clay.
Bt	18 - 40"	greyish brown (10YR-5/2) prismatic to blocky, hard, clay.
Csa	40"+	light brownish grey (10YR-6/2) stratified clay and silt, some salt crystals.

B. Materials Used in Soil Column Experiment

Figure 4 shows two of the eight columns studied in this experiment. The columns which were made from 1/4" transparent plastic measure 4 x 5 x 20". A 3/4" hole was made in the base of each column. Leachate from the soil was caught in plastic baskets 15" high for columns 2 and 5 and in pyrex glass plates for the rest of the columns. A brown paper cover over each column discouraged the growth of algae. Four $\frac{1}{2}$" stoppered holes in one side allowed the insertion of an electrode to measure pH at various depths. Copper wire leads from eight platinized platinum wire electrodes prepared as outlined by Quispel (42) protrude from the tops of the columns.

The columns contain a calcareous till parent material, the C horizon of profile 3 from site II. This soil was ground to pass through a 2 mm. sieve, thoroughly mixed and poured into the columns. Columns 1 to 6 each contained 5,700 gm. of air dry soil. A pad of glass wool and a half inch layer of Ottawa sand prevented the soil from escaping through the hole at the base of the columns.

In two of the columns, numbers 7 and 8, Ottawa sand was mixed with the soil. Column 7 contained 1000 gm. soil and 6,270 gm. sand, column 8 contained 400 gm. soil and 7,250 gm. sand.

Column 4

Column 5

Figure 4. (Leaves, freely drained)

(no leaves, fluctuating water table)

Ground leaves, mainly aspen, were placed on top of the soil in columns 1, 2, 3, 4, 7, and 8. The leaves used during the first eight months were raked from the ground in December, two months after leaf fall. Those used since October 1956 were picked from the trees during leaf-fall in October.

Glass wool was placed on top of the soil in columns 5 and 6. This was done to reduce surface evaporation to a rate similar to that from the columns having ground leaves at the surface.

C. Procedure with Soil Columns

The columns of soil were maintained under varying moisture conditions as follows:

Column 1 Saturated. The stopper was removed from the base of the column and free drainage was allowed for two hours once each week.

Columns 2 and 5 Fluctuating water table. Saturated conditions to within 9" of the soil surface were maintained for four weeks, and then free drainage was maintained for four weeks.

Columns 3 and 7 Water table 18" from the surface.

Columns 4, 6, and 8 Freely drained.

Water was added to the columns four times per week. For the first few weeks, varying amounts were added, but during most of the course of the experiment 250 c.c. was added at each watering. The water table was brought to the surface of column 1 each time water was added. To

prevent precipitation of salts due to evaporation of leachates, 150 c.c. of water was added each week to the receiving vessels at the base of the columns. This procedure was started after the second month when precipitated salts were noticed in some of the receiving dishes.

The leachate was collected each week. Periodically its pH was measured and at intervals an aliquot was taken for HCO_3^- analysis. The remainder of the leachate was evaporated to a small volume, and later combined with three succeeding leachates from the same column. The leachate for a four week period was then made up to volume, a drop of toluene was added, and it was stored for analysis. For the first 15 months all the leachate was saved for analysis. Subsequently, the leachate was saved one month out of every three or four.

Platinized platinum electrodes were used to measure E_h of the soil in the columns. They were inserted by making a hole in the moist soil with a sealed glass tube. The electrode was then pushed an inch below the depth of the hole so that the platinum wire made contact with the soil. Duplicate electrodes were inserted at depths of 1, 5, 9, and 15 inches below the surface of the soil and left in place.

Some procedures with the columns did not conform to a rigid routine. E_h readings were taken periodically, weekly for the first three months. A Beckman model H_2 pH meter with a saturated calomel electrode was used to

make these measurements. The calomel electrode was pushed into the surface of the moist soil at the top of the column. Periodic attempts were made to measure pH at various depths by putting a glass electrode into one of the holes in the side of the columns. A saturated calomel reference electrode was used. It was impossible to get stable readings. Because of this, and since pH apparently varied little, results are not reported. Observations were made periodically to determine whether any morphological changes in the soil were evident. Ground leaves were added to the surface of the columns three or four times a year after previously added leaves had decomposed appreciably. Total weights of air dry leaves added to the columns were as follows:

Column 1 - 100 gm.

Columns 2, 3, and 4 - 150 gm.

Columns 5 and 6 - 0 gm.

Columns 7 and 8 - 110 gm.

D. Methods of Analysis of Soil Column Leachates

Combined leachate concentrates from each column for a four week period were made up to 500 ml. A 200 ml. aliquot was taken for inorganic analysis. Organic matter was removed by digesting with a mixture of nitric and perchloric acids. The residue was taken up in two successive portions of concentrated HCl and evaporated to dryness to decompose the perchloric acid. Residues were dissolved in 1 N HCl and after filtering, the solutions were made up to a volume of 50 ml. Aliquots of these solutions were taken for the

determination of Na, K, Mg, Ca, Fe, Al, and SO_4.

The methods of analysis employed were ones commonly used by soil scientists. Na and K were determined with a Beckman DU spectrophotometer with a model "9200" flame attachment. The procedure used was that outlined by Pawluk and Bentley (39). Ca was separated from Mg by precipitating it as CaC_2O_4. Mg was determined by a versenate titration and Ca by a permanganate titration as outlined by Pawluk and Bentley (39). Fe was determined colorimetrically after developing the color with ortho-phenanthroline. The procedure used was one outlined by the Soil Science Department of the University of Alberta. Al was determined colorimetrically by Robertson's (43) hydroxylamine hydrochloride method. The color was developed with "aluminon". SO_4 was determined turbidimetrically after precipitation as $BaSO_4$ according to a procedure used by the Soil Science Department of the University of Alberta. A Bausch and Lomb "Spectronic 20" colorimeter was used for the colorimetric and turbidimetric measurements.

E. Methods of Analysis of Soil Samples

Soil samples were air dried, crushed to pass a 2 mm. sieve and stored for analysis.

pH A Beckman model H_2 pH meter was used to measure the pH of the saturated soil paste.

N Nitrogen was determined by a macro Kjeldahl method similar to that outlined by Prince (41). The NH_3 was distilled into boric acid solution.

C Total carbon was determined by the A.O.A.C. (2) dry combustion method.

Inorganic C Inorganic C was determined in some calcareous samples by a modified Schollenberger (47) method. CO_2 was evolved by heating the sample in dilute HCl containing $SnCl_2$.

P Phosphorus was determined in a few samples. The soil was fused with Na_2CO_3 and a colorimetric method involving ammonium molybdate was used to determine phosphorus. (58).

Exchange Analysis Cation exchange capacity and exchangeable cations were determined by an adaptation of the ammonium acetate method as described by Pawluk and Bentley (39).

Mechanical Analysis A modified pipette method as outlined by Toogood (57) was used.

"Free" iron Sodium hydrosulphite was used to remove the "free" iron and the color was developed with sodium salicylate according to the procedure described by Mackenzie (35).

Total iron The sample was fused with HF and H_2SO_4. $HClO_4$ was used to destroy organic matter. Iron was determined colorimetrically with ortho-phenanthroline as outlined by Shapiro and Brannock (51).

V. RESULTS AND DISCUSSION OF LABORATORY STUDY

A. Redox Potentials

Tables Ia and Ib show a few sets of redox potential measurements. These were selected to show the variability of, and trends in, the Eh readings. To facilitate interpretation of these, and subsequent tables, a summary of the make-up and treatment of each column is given.

Column 1. - Saturated, leaves at surface.
Column 2. - Fluctuating water table, leaves.
Column 3. - Water table at 15 inches, leaves.
Column 4. - Freely drained, leaves.
Column 5. - Fluctuating water table, no leaves.
Column 6. - Freely drained, no leaves.
Column 7. - Water table at 15 inches, 86% sand with soil, leaves.
Column 8. - Freely drained, 95% sand with soil, leaves.

TABLE Ia

Duplicate Eh (mv.) Readings at Four Depths in Columns 1, 2, 3, and 4

	Depth	Column 1	Column 2	Column 3	Column 4
Feb. 18, 1956	1"	-130, -150	-120, -100	540, 90	-230, -340
	5"	-300, -360	-90 , -80	-330, -280	0 , -270
	9"	-350, -360	-150, -90	630, 640	570, 90
	15"	-200, -120	520, 520	610, 580	540, 570
May 10, 1956	1"	-240, -210	470, -150	640, 560	550, 500
	5"	-200, -10	-180, -230	-130, 490	590, 360
	9"	-90, -170	420, 450	640, 660	590, 550
	15"	-100, -120	550, 480	640, 630	620, 640
Dec. 24, 1956	1"	-230, -130	610, 570	710, 650	660, 660
	5"	-180, -180	150, 590	570, 620	670, 640
	9"	-180, -190	560, 560	690, 700	680, 660
	15"	-130, -160	630, 580	690, 690	700, 690
Jan. 4 1958	1"	-220, -260	630, 570	730, 680	680, 690
	5"	-230, -220	190, 570	660, 530	670, 660
	9"	-190, -180	440, 160	710, 710	700, 670
	15"	-160, -160	440, 470	570, 660	700, 690

TABLE Ib

Duplicate Eh (mv.) Readings at Four Depths in Columns 5, 6, 7, and 8

	Depth	Column 5	Column 6	Column 7	Column 8
Feb. 18, 1956	1"	560, 540	550, 560	540, 600	610, 580
	5"	540, 570	560, 570	650, 620	550, 600
	9"	520, 550	550, 550	610, 630	640, 650
	15"	560, 570	560, 570	640, 640	620, 610
Sept. 7, 1956	1"	640, 650	650, 650	640, 610	620, 620
	5"	610, 650	580, 590	620, 640	590, 620
	9"	590, 670	660, 590	620, 660	650, 640
	15"	650, 660	640, 670	580, 660	650, 650
July 1, 1957	1"	650, 660	600, 670	650, 660	650, 660
	5"	680, 700	670, 570	640, 650	650, 650
	9"	660, 540	680, 680	670, 670	640, 660
	15"	650, 670	630, 660	660, 660	680, 660

Table Ia shows that Eh readings for columns 1, 2, 3, and 4 were erratic for the first several months. By December 1956, Eh values had become relatively stable and subsequently Eh readings were consistent. It is apparent that strongly reducing conditions, averaging

about -200 mv., prevailed in Column 1. Columns 3 and 4 maintained high redox potentials - about 650 mv. Eh readings for Column 2 were more variable and somewhat lower than those for Columns 3 and 4. The erratic nature of the early Eh readings is not surprising. The soil material used in the columns was from a C horizon. It was not in equilibrium under the conditions of the experiment. It is also possible that in some cases fragments of organic matter were washed down to the vicinity of the electrodes. This would result in unusually low readings due to the reduction of the organic matter. The failure of duplicate electrode readings to agree was to be expected. Most workers who have made in situ measurements of soil Eh have reported poor agreement of duplicates (26, 36, 42). Eh values reported are within the limits of those generally reported, -300 mv. to +700 mv. (4). It should be noted that these readings were not corrected for pH. Usually Eh is corrected to a standard pH - often 7. This was not done as the pH at various depths in the columns was not known. However, if a pH of 8 is assumed and if the pH to Eh relationship of the soil is assumed to be 60 mv. (4, 52) then the addition of 60 mv. to each reading would correct the readings to pH 7.

Table Ib shows that Eh values for columns 5, 6, 7, and 8 remained relatively stable and high throughout the experiment. Ground leaves were not added to columns 5 and 6 so little readily oxidizable material was present.

Probably the large proportion of sand in columns 7 and 8 permitted such good aeration that highly oxidized conditions always prevailed even with organic matter at the surface. A comparison of Eh readings for columns 5 and 6 with those for columns 3, 4, 7, and 8 illustrates that the presence of ground leaves at the surface does not lower Eh unless high water table conditions prevail.

TABLE II

Effect of Fluctuating Water Table on Eh (mv.) (Eh values are averages of 2 electrode readings)

	Column 2				Column 5			
Time	1"	5"	9"	15"	1"	5"	9"	15"
4 wks. F.D.*	250	70	635	665	630	650	630	665
1 wk. H.W.T.**	235	20	515	590	635	645	610	650
2 wks. H.W.T.	215	-5	455	495	655	685	660	670
3 wks H.W.T.	235	20	435	455	No reading.			
4 wks. H.W.T.	285	45	355	4.5	650	690	655	660
1 wk. F.D.	320	285	565	645	625	660	640	640
2 wks. F.D.	365	350	600	665	635	665	650	665

*F. D. - free drainage.

** H. W. T. - high water table.

Table II shows that the effect of fluctuating water table on Eh of the columns depends upon the presence or absence of ground leaves at the surface. In column 2, the one with ground leaves, Eh at the electrodes below the water table decreased steadily with duration of the high water table and increased rapidly when the water table was lowered. Eh at one inch was not affected by the changes in water table. Eh at five inches - just above the water table, was erratic. Readings tended to be lower when the high water table was present - particularly soon after the addition of leaves. The reason for the relatively low Eh readings at five inches is not clear. The reading for one of the electrodes was always low and changing the electrode made no difference. In column 5, the one without ground leaves, water table had no effect on Eh.

The results of the Eh measurements can be summarized as follows:

1. If ground leaves were present, high water table resulted in a marked lowering of Eh of the soil below the water table.
2. High water table had no effect on the Eh of soil in the columns if ground leaves were not present.
3. Under continuously saturated conditions, with ground leaves at the surface, the soil developed a fairly stable, low redox potential averaging about -200 mv.

4. Freely drained soil columns with or without ground leaves at the surface had an Eh of about +650 mv.

These results agree in general with those of other workers who have studied soil Eh (42, 52). Their application will be mentioned in the discussion of field studies.

B. Leachate Analysis

Table III shows data of analysis of the soil column leachates for four separate four-week periods. Many of the trends in leachate composition are more clearly shown by subsequent tables. However, some comments are appropriate at this point.

1. After the first four-week period, the total cation content of the leachates from columns 2, 3, and 4 exceeds that of the leachates from the other columns. The reasons are: (a) column 1 was kept saturated and drained once a week. Thus only a small quantity of water passed through this column. (b) columns 5 and 6 had no leaves at the surface. (c) columns 7 and 8 contained large proportions of quartz sand. This relationship was not clear for the first four-week period as nearly all the soluble Na^+ was removed during this interval.

2. During the last two periods shown in Table III the HCO_3^- content of the leachates was approximately equal to the sum of cations. After the first month, the $SO_4^=$ content of the leachates was low.

TABLE III

Ions Leached From Soil Columns

Date	No.	m.eq./4 weeks Ca++	Mg++	Na+	K+	Sum Cations	$SO_4^=$	HCO_3^-	Sum Anions	mgm./4 weeks Fe	Al
Feb	1	3.7	19.6	28.5	0.8	52.6	9.0			3.70	0.48
17-	2	4.3	21.5	25.0	0.9	51.7	10.3			0.94	1.38
Mar	3	4.4	23.9	37.5	1.5	67.3	13.5			0.15	0.18
17/56	4	3.3	24.0	35.0	1.4	63.7	13.6			0.28	0.33
(start	5	3.3	12.2	31.0	1.3	47.8	10.3			0.11	0.06
of exp.	6	4.0	15.9	32.5	1.2	53.6	14.8			0.14	0.77
Feb 17)	7	2.8	9.0	13.3	0.8	25.9	5.3			0.72	0.49
	8	2.6	7.9	6.2	0.7	17.4	3.3			1.20	0.74
July	1	1.6	7.6	4.2	.3	13.7				2.10	0.36
9 -	2	4.8	18.1	1.2	.9	25.0				0.23	0.36
Aug	3	4.0	15.5	0.9	1.1	21.5				0.12	0.26
6/56	4	4.4	16.5	0.9	1.1	22.9				0.03	0.21
(lea-	5	2.4	8.3	4.9	1.0	16.6				0.18	0.69
ves	6	2.5	8.9	4.5	0.9	16.8				0.09	0.22
added	7	3.1	5.8	0.5	0.7	10.1				0.12	0.28
May 12.	8	4.0	3.3	0.5	0.3	8.1				0.09	0.18
April	1	1.9	7.6	0.3	0.2	10.0	0.2	12.3	12.5	1.80	0.19
15-	2	4.0	10.0	0.3	0.7	16.0	0.4	16.7	17.1	0.39	0.62
May	3	4.0	9.8	0.3	0.6	14.7	0.3	15.4	15.7	0.12	0.33
13/57	4	4.1	9.6	0.3	0.6	14.6	0.3	15.3	15.6	0.09	0.37
leaves	5	1.9	4.7	0.6	0.6	7.8	0.2	9.0	9.2	0.14	0.43
added	6	1.9	4.4	0.6	0.4	7.3	0.2	7.9	8.1	0.09	0.31
Feb 18)	7	3.8	2.3	0.3	0.6	7.0	0.1	7.3	7.4	0.26	0.39
	8	5.2	1.0	0.3	0.6	7.1	0.1	6.9	7.0	0.26	0.28
Oct	1	1.7	4.9	0.4	0.2	7.2	0.2	7.7	7.9	0.56*	0.25
26-	2	7.1	18.4	0.3	0.9	26.7	1.3	26.1	27.4	0.54	0.50
Nov	3	7.6	15.9	0.2	0.9	24.6	1.4	25.7	27.1	0.22	0.38
23/57	4	5.9	15.8	0.3	0.8	22.8	1.6	22.3	23.9	0.10	0.25
leaves	5	2.1	4.2	0.5	0.4	7.2	0.1	7.2	7.3	0.16	0.58
added	6	1.8	3.8	0.5	0.3	6.4	0.1	7.2	7.3	0.08	0.18
Oct	7	7.4	2.8	0.3	0.5	11.0	0.7	10.4	11.1	0.16	0.40
26)	8	8.6	2.0	0.1	0.2	10.9	0.6	11.6	12.2	1.02	0.38

* This result is probably in error. Fe removed the previous month was 1.6 mgm. and during a subsequent month it was 1.3 mgm.

3. The iron and aluminum content of the leachates was low. For this reason, results for these elements are expressed in mgm. rather than m.eq.

TABLE IVa

Ca^{++}(m.eq.) Leached From Columns During 24-week periods

	1	2	3	4	5	6	7	8
Feb 16-Aug 6/56	13.6	24.4	23.7	23.3	13.5	15.6	20.5	22.1
Aug 6/56 Jan 21/57	12.0	23.7	24.1	22.5	14.0	14.6	25.6	31.3
Jan 21-July 8/57*	11.6	26.7	26.9	23.7	11.9	11.9	25.5	36.3
July 8-Dec 23/57**	10.6	29.8	33.6	30.2	13.4	13.2	34.0	36.4
Sum -	47.8	104.6	108.3	99.7	52.8	55.3	105.6	126.1

TABLE IVb

Mg^{++}(m.eq.) Leached From Soil Columns During 24-week Periods

	1	2	3	4	5	6	7	8
Feb 16-Aug 6/56	66.4	103.8	108.6	110.1	41.3	51.8	52.1	37.3
Aug 6/56 Jan 21/57	52.2	74.9	78.8	72.9	44.6	45.7	32.7	13.1
Jan 21-July 3/57*	47.1	72.6	72.1	66.1	31.2	29.7	18.1	7.4
July 8-Dec 23/57**	36.6	74.0	70.2	71.6	20.4	28.8	14.0	8.0
Sum -	202.3	325.3	329.7	320.7	147.5	156.0	116.9	65.8

* Data for 16 weeks were extrapolated to cover the 24-week period.

** Data for 8 weeks were extrapolated to cover the 24-week period.

TABLE IVc

Na^+(m.eq.) Leached From Columns During 24-week Periods

	1	2	3	4	5	6	7	8
Feb 16-Aug 6/56	73.2	82.7	84.0	80.9	81.2	85.5	17.2	8.6
Aug 6/56-Jan 21/57	10.0	4.1	3.3	3.3	9.8	8.5	3.1	3.0
Jan 21-July 8/57*	2.2	2.0	1.8	1.9	4.0	4.3	2.1	2.0
July 8-Dec 23/57**	1.6	1.8	1.6	1.8	3.4	4.2	2.0	1.0
Sum -	87.0	90.6	90.7	87.9	98.4	102.5	24.4	14.6

TABLE IVd

K^+(m.eq.) Leached From Columns During 24-week Periods

	1	2	3	4	5	6	7	8
Feb 16-Aug 6/56	2.5	5.4	7.1	7.3	5.3	5.8	4.8	3.8
Aug 6/56-Jan 21/57	2.6	5.2	5.7	6.3	5.9	5.6	3.8	4.4
Jan 21-July 8/57*	1.2	4.4	4.2	4.0	3.7	3.0	4.6	3.9
July 8-Dec 23/57**	1.2	4.2	4.6	4.4	2.8	2.6	3.4	2.4
Sum -	7.5	19.2	21.6	22.0	17.7	17.0	16.6	14.5

* Data for 16 weeks were extrapolated to cover the 24-week period.

** Data for 8 weeks were extrapolated to cover the 24-week period.

TABLE IVe

Fe (mgm.) Leached From Soil Columns During 24-week Periods

	1	2	3	4	5	6	7	8
Feb 16-Aug 6/56	15.9	2.1	.8	.8	1.4	.5	1.6	1.9
Aug 6/56-Jan21/57	19.7	1.7	.8	.6	.6	.6	1.3	2.8
Jan 21-July 8/57*	13.3	2.2	.7	.5	1.1	.6	1.3	2.0
July 8-Dec23/57**	10.0	1.8	1.1	.7	1.4	.7	.9	2.8
Sum -	58.9	7.8	3.4	2.6	4.5	2.4	5.1	9.5

TABLE IVf

Al(mgm.) Leached From Soil Columns During 24-week Periods

	1	2	3	4	5	6	7	8
Feb 16-Aug 6/56	3.3	4.2	1.4	1.9	3.3	1.9	2.2	2.1
Aug 6/56-Jan 21/57	1.4	3.0	1.5	1.2	2.2	1.4	1.8	1.6
Jan 21-July 8/57*	1.2	3.3	1.8	1.8	2.3	1.6	2.0	1.6
July 8-Dec23/57**	1.5	6.1	2.3	2.3	4.9	1.7	2.6	2.2
Sum -	7.4	16.6	7.0	7.2	12.7	6.6	8.6	7.5

* Data for 16 weeks were extrapolated to cover tha 24-week period.

** Data for 8 weeks were extrapolated to cover the 24-week period.

Tables IVa to IVf show the changes in amounts of various individual ions in the leachates during four 24-week periods. The main trends shown by each of the tables are listed.

IVa Ca^{++} content of the leachates remained fairly constant for columns 1 - 6 and increased for columns 7 and 8. More Ca^{++} was removed from column 8 than from any other column. Leachates from columns 5 and 6 were low in Ca^{++}.

IVb For the columns with leaves, Mg^{++} in the leachates decreased sharply after the first 24-week period and then continued to decline or became fairly stable. The decrease in Mg^{++} was most striking in leachates from columns 7 and 8. As removal of Mg^{++} from these columns decreased, removal of Ca^{++} increased. Mg^{++} removal from columns 5 and 6 was relatively slow. It is probable that Mg^{++} and Ca^{++} in the leachates were derived from the carbonates of these elements. The $CaCO_3$ equivalent of the soil used in the columns was 6.8% and the HCO_3^- content of the leachates was relatively high. As $MgCO_3$ is more soluble in water than $CaCO_3$ it is reasonable that Mg^{++} is removed more rapidly than Ca^{++}. This is in no way at variance with the results of Atkinson and Wright (3) who found that when calcareous sand was leached with E D T A, the Ca/Mg ratio in the leachate tended to decrease with time. Ca-E D T A is more stable than Mg- E D T A; thus it is removed more rapidly in the chelate form. Leaf decomposition products may also act as chelates, but probably in this experiment the solution action of water and organic acids was of more significance in the removal of ions.

IVc Most of the soluble Na^+ was leached from the columns during the first 24-week period. Subsequently Na^+ removal slowly decreased. Total Na^+ removed was similar for columns 1, 2, 3, and 4, and higher for columns 5 and 6. The extra Na^+ in the leachates of columns 5 and 6 may be accounted for by the solution of glass wool which was placed at the surface of these columns. Data on this are given in Table VIII.

IVd K^+ content of the leachates was low and generally it diminished slowly with time.

IVe Fe removed from column 1 was far greater than that removed from any other column. This was to be expected as column 1 was under strong reducing conditions. Statistical analysis by means of t tests indicated that Fe removed from column 2 was significantly greater at the 1% level than that removed from columns 3 and 4. However, the amounts of iron removed from columns 2 and 5 weren't quite significantly different at the 5% level. This may indicate that the large amount of water used to provide a high water table had more influence on the amount of iron in the leachate of column 2 than did the lowered Eh resulting from the high water table. During high water table periods the Eh below the water table in column 2 was usually about 400 mv. This is too high an Eh for appreciable reduction of Fe to take place (52).

Fe removed from column 8 was significantly higher than that removed from any other column except 1 and 2. Possibly iron brought into solution in the upper portions of other columns was immobilized lower in the profile by a mechanism

such as the one suggested by Bloomfield (13). Less immobilization of iron would be expected in column 8 as such a large proportion of the material was quartz sand.

IVf Aluminum content of the leachates was somewhat erratic. The leachates of columns 2 and 5 - the ones with fluctuating water tables, were highest in aluminum. Because of the water tables, more water was processed for analysis from these than from the other columns. As shown in Table X, the distilled water contained some aluminum. This may account for the higher amounts of aluminum in the leachates of columns 2 and 5. However, the values reported were corrected for this error as accurately as possible.

TABLE V

Effect of Addition of Ground Leaves on Removal of Ca and Mg From Columns 3 and 8

Date	Time Since Leaves added	Column 3 Ca	Column 3 Mg	Column 8 Ca	Column 8 Mg
Oct 1-29/56	24 weeks	3.2	9.9	3.8	1.7
Oct 29-Nov 26/56	0 weeks	4.8	15.5	9.3	3.9
Jan 21-Feb 18/57	8 weeks	4.5	13.9	4.5	.9
Feb 18-Mar 18/57	0 weeks	5.4	15.7	8.9	2.3
Aug 4-Sept 1/57	24 weeks	4.6	9.6	4.8	1.0
Oct 26-Nov 23/57	0 weeks	7.6	15.9	8.6	2.0

TABLE VI

Ions Leached From 50 gm. Ground Leaves

	m.eq.						mgm.	
Time	Ca	Mg	Na	K	Sum of Cations	SO_4	Fe	Al
0 - 4 weeks	9.3	7.5	0.1	6.0	22.9	2.9	1.2	0.25
4 - 8 weeks	1.3	.7	tr.	0.1	2.1	0.1	0.1	0.15
8 - 12 weeks	0.2	0.1	tr.	tr.	0.3	tr.		
12 - 16 weeks	0.2	0.1	tr.	tr.	0.3	tr.		

Table V illustrates the marked effect of addition of fresh ground leaves on the Ca^{++} and Mg^{++} of the leachates. Column 8 is affected to a greater degree than column 3. This is probably due to the lower adsorbing capacity of column 8. Leachates from columns 2 and 4 were affected by added leaves as was column 3. Column 7 leachates were affected almost as strikingly as column 8.

Table VI shows part of the reason for the effect of added leaves. Considerable quantities of Ca^{++}, Mg^{+}, and K^{+} are leached from the leaves. Bloomfield (12) found that the total Ca^{++} and Mg^{++} content of aspen leaves was high. Probably organic acids and other substances leached from the leaves also contributed to the increased quantities of Ca^{++} and Mg^{++} in the leachates. As the K^{+} content of the leachates wasn't much affected by leaf additions, it must be assumed the K^{+} was adsorbed by the soil. $SO_4^{=}$ was increased by leaf additions as shown by Table III.

C. Soluble Salt Content of Soil Used in Columns

TABLE VII

Soluble Salts (m.eq. per 100 gm. soil in 1:5 extract)

$SO_4^{=}$	$CO_3^{=}$	Cl^-	HCO_3^-	Na^+	K^+	Mg^{++}	Ca^{++}
0.5	nil	nil	1.1	1.2	tr.	0.4	.05

Data in Table VII are generally consistent with those of Table III. If it is assumed that all soluble Na^+ was removed by this extraction, then in the 5,700 gm. of soil in the columns, 57 x 1.2 = 68.4 m.eq. of soluble Na^+ would be present. This is somewhat lower than the total Na^+ values shown in Table IVc. The difference can be partially accounted for by the Na^+ present in the leaves and Na^+ released from the small pad of glass wool at the base of each column. Furthermore, prolonged leaching may have brought about breakdown of some sodium containing minerals.

D. Problems in Leachate Analysis

TABLE VIII

Na^+ Leached from 5 gm. of Glass Wool

Month 1	1.1 m.eq.
Month 2	0.4 m.eq.

The consistently high Na^+ content of the leachates from columns 5 and 6 led to suspicion that Na^+ was being released by the breakdown of glass wool which was added to the top of these columns to limit evaporation. 5 gm. of glass wool was put into a funnel and it was leached with 1 liter of water a week as were the soil columns. Table VIII shows that

significant amounts of sodium were released by the glass wool.

TABLE IX

Na and K Dissolved From Beads Used in Perchloric Acid Digestions

	m.eq. Na^+	m.eq. K^+
Beads 'a'	less than 0.01	less than 0.01
Beads 'a'	less than 0.01	less than 0.01
Beads 'b'	0.45	1.0
Beads 'b'	0.45	0.9

Table IX illustrates the importance of using resistant glass beads in perchloric acid digestions. When beads 'b' were substituted for beads 'a' in the preparation of leachates for analysis, values for Na^+ and K^+ in the leachates jumped markedly. Duplicate blank perchloric acid digestions were done with beads 'a' and beads 'b'. The results are shown in Table IX. Beads 'b' were noticeably etched while beads 'a' did not appear to have been attacked.

TABLE X

Variations in Al Content of Distilled Water

	Al (microgm. per l.)
August 16, 1957	60
Fri., Dec. 5, 4:PM	24
Mon., Dec. 8, 8:AM	56

Table X is the result of an attempt to account for erratic results in the determination of aluminum in the leachates. The amount of aluminum in the distilled water varied from time to time. This can be accounted for by the fact that the distilled water flowed through aluminum pipes. After a week end, December 5 - December 8, of standing in the pipes, the distilled water contained considerably more aluminum than it did on December 5 after a week of steady use. As the amount of aluminum in the water varied, it was impossible to make an accurate correction for it. Since water was usually added in the morning, a correction term of 60 micrograms aluminum per liter of water used, was subtracted from each aluminum value determined.

E. Miscellaneous Data on Soil Columns

1. pH of a saturated paste of the soil used in the columns was 8.4. pH of the leachates from the columns was not measured for the first six months of the experiment. Since then, pH's of the leachates have varied little. Average values are as follows:

Column 1 - 7.9 ± .1

Column 2 - 8.0 ± .2(H.W.T)*, 8.5 ± .3 (F.D.)**

Column 3 - 8.5 ± .2

Column 4 - 8.6 ± .2

Column 5 - 8.1 ± .1 (H.W.T.), 8.6 ± .1 (F.D.)

Column 6 - 8.7 ± .1

Column 7 - 8.3 ± .2

Column 8 - 8.3 ± .2

*H.W.T. - High water table.

** F. D. - Freely drained.

Probably the pH of the leachate from column 1 was relatively low because of a higher concentration of leaf decomposition profucts. Lower concentrations of alkali and alkaline earth ions probably account for the slightly lower pH's of the leachates from columns 7 and 8.

2. Approximate amounts of water evaporated from the surfaces of the columns and from the receiving vessels are shown below:

Column 1 - not measured.

Column 2 - 250 ml./wk.

Column 3 - 240 ml./wk.

Column 4 - 250 ml./wk.

Column 5 - 280 ml./wk.

Column 6 - 330 ml./wk.

Column 7 - 210 ml./wk.

Column 8 - 200 ml./wk.

Two factors may account for the higher evaporation from columns 5 and 6; (a) low permeability resulted in standing water at the surface for several hours after watering. (b) glass wool was not as effective a mulch as

leaves. The relatively low evaporation from columns 7 and 8 was likely due to restricted upward movement of water because of the high content of coarse sand in the columns.

F. Observations Regarding Soil Columns

1. After one month, the drab grey color characteristic of gleyed soils had become apparent in column 1. The observable gley characteristics increased with time. These included: (a) a general dull grey color (b) dark grey blotches - possibly due to sulfides (c) grey patches surrounded by yellowish-brown bands. The drab grey color was probably due to the removal of ferric oxide coatings under the strong reducing conditions which prevailed in this saturated column. Yellowish-brown patches probably resulted from the oxidation of Fe^{++} during the two hour period each week when the column was drained.

2. After one month, a breakdown of 2 mm. crumbs could be observed near the surface of most of the columns. This slaking became more apparent with time. It was probably due, at least partially, to the solution of cementing carbonate salts.

3. Leachates from all columns - including 5 and 6 which were without ground leaves, were intensely yellow in color for the first three or four months. The color became lighter as time progressed. Additions of ground leaves resulted in more intensely colored leachates for a month or two. If the

color was due to soluble organic matter, it is difficult to rationalize the initial strong color of leachates from columns 5 and 6. The soil used in the columns was a parent material with a nitrogen content of 0.04%.

4. After three months of leaching, it became apparent that the soil material in column 8 was accumulating in irregular bands. This banding or blotching increased as leaching proceeded. After two years, little soil remained in the top five inches of the column. Banding also occurred in column 7. Figure 5 shows columns 7 and 8 after 15 months of leaching. The banding probably resulted from mechanical movement of fine particles of soil material through the coarse sand. The fine material was deposited in zones of local concentration of fine particles due to imperfect mixing of sand and soil. Once a band of finer material developed, it would act as a filter and accumulate more soil material. Such a mechanism may be partially responsible for clay movement in coarse textured soils. It is also conceivable that processes other than mechanical movement were at least partially responsible for the phenomenon discussed. Several mechanisms of clay transport and deposition are suggested in the literature. (15, 25, 29).

5. After twenty months of treatment, it was observed that following a month of high water table, column 2 was appreciably yellower above the water table than below it.

Figure 5. Columns 7 and 8 after 15 months of leaching.

A fairly distinct line could be observed about six inches from the surface, separating greyish soil below from yellowish-grey soil above. The color difference gradually faded after the water table was removed and intensified during the succeeding high water table periods. The greying may have been due to reduction of ferric oxide coatings. During high water table periods, the average Eh below the water table in column 2 was about 400 mv. Starkey and Wight (52) indicate that 200 to 400 mv. is the range of slightly reducing conditions in soil. Thus marked evidence of gleying would not be expected in column 2.

6. Columns 5 and 6 became decreasingly permeable as leaching proceeded. After two years of leaching, permeability had decreased from about one inch per hour to about one inch per 24 hours. Some disintegration of the glass wool which was placed at the surface of the soil had taken place. The glass wool was replaced by cleaned Ottawa sand after two years of leaching. Table VIII shows that Na^+ is released from glass wool which is leached with distilled water. It is possible that Na^+ from this source caused dispersion of the soil near the surface of columns 5 and 6. This would result in low permeability. However, since the soil was fairly high in calcium and magnesium carbonates and since the amount of Na^+ released by glass wool was low, it seems unlikely that dispersion would be effected.

G. Summary and General Discussion of Laboratory Study

This laboratory study was set up to provide some information on (a) the effects on redox potential, (b) the effects on leaching of various elements, and (c) the effects on morphology, when soil material is subjected to different drainage conditions. It was hoped that some of the information obtained would be of use in interpreting the characteristics of poorly drained soils. The main results of the study are summarized:

1. If organic matter was present, high water tables resulted in reducing conditions below the water table.

2. Low redox potentials were associated with relatively high rates of iron removal. Redox potential had no effect on the removal of other ions determined.

3. Of the ions determined in the leachates, most of the Na^+ and $SO_4^=$ were removed rapidly. K^+ content of the leachates was low and it decreased slowly with time. Mg^{++} was removed more rapidly than Ca^{++}. With time, the ratio of Mg^{++} to Ca^{++} in the leachates decreased. Generally, iron and aluminum content of the leachates was low. After the first month, when most of the $SO_4^=$ was removed, the amount of HCO_3^- in the leachates approximately equalled the sum of Na^+, K^+, Mg^{++} and Ca^{++}.

3. Ground leaves on the surface markedly increased the amounts of Mg^{++}, Ca^{++}, and HCO_3^- in the leachates, but had little effect upon the removal of K^+, iron and aluminum.

4. If leaching of HCO_3^- continued at a steady average rate of about 4.3 m.eq. per week, in columns 2, 3, and 4, it would take about 35 years to completely remove carbonates. Similarly, for column 8, it would take nearly six years to completely remove carbonates. These rates of carbonate removal occurred when the net percolation of water was about 10 feet per year.

5. Morphological evidences of gleying soon became apparent when reducing conditions were imposed.

Some of the results of the laboratory study are difficult to explain. The work of Bloomfield (12) and Schnitzer and De Long (50) suggested that more iron and aluminum would be removed from columns with leaves at the surface than from those without leaves. Leachate analysis did not bear this out. It is possible that sesquioxides mobilized by constituents from the leaves were immobilized lower in the columns by mechanisms discussed by these authors, (13, 24). If this is so, analysis of the soil from the columns may show evidence of sesquioxide eluviation and illuviation.

The make-up and treatment of columns 2, 3, and 4 differed only in water table conditions. It seemed probable that there would be a direct relationship between the amounts of ions removed from these columns and the heights of water tables maintained. Thus, it was expected that the total cation content of leachates from column 2 would exceed that of column 3, and that column 3 leachates would exceed those from column 4 in total cation content. Tables IVa, IVb, IVc, and IVd indicate that this relationship did not exist, although there is a slight tendency for the cation content of column 4 leachates to be somewhat lower than the others. To provide the high water table every second month in column 2, eight litres of water was added to the basket which contained the column. The low water table in column 3 was maintained by adding 250 c.c. extra water each week to the plate at the base of the column. It appears that this water had little solution effect on constituents of the soil in the columns, and that only the water which was added at the surface of the column played a significant role in removing substances from the soil. The same relationship holds for columns 5 and 6 which had no leaves at the surface. Relating this to field conditions leads to the tentative conclusion that periodic high water table conditions without an increase in the amount of water passing through the profile would have little effect upon the removal of carbonates and other somewhat soluble substances from the soil.

This laboratory study has yielded some quantitative information on the effect of drainage conditions on Eh, removal of ions, and morphology of soil material maintained under specified conditions. Caution must be exercised in applying these results to field conditions as the natural environment of a soil profile is much more complicated and varied than was the environment of these columns. Nevertheless, this general approach to the study of soil development is promising. The factors of soil formation can be controlled in the laboratory and studied in isolation. Only the insight of the worker who designs the experiment limits the possible gains in understanding of soil genesis which can result from the application of this approach together with study of soil in the field.

VI. RESULTS AND DISCUSSION OF FIELD STUDY

A. Results of Analysis of Profiles

Analytical results from the field study are presented in Tables XI to XV. These tables follow in sequence.

TABLE XIa

Analysis of Profiles from Site I

Horizon	Depth	pH	%N	%C	C/N	Exchangeable Cations m.eq./100 gm. H	Na	K	Mg	Ca	Total CEC by Sum	by Deter.	Mechanical Analysis %S	%Si	%C
Profile 1 - Slough Podzol															
O	3-0"	5.6	0.79	11.40	14.4										
Ahe	0-1"	5.8	0.22	2.66	12.1	4.0	0.3	0.9	4.0	7.8	17.0	15.3	21	63	16
Aeg	1-3½"	6.0	0.06	.48	8.0	1.5	0.2	0.6	1.5	3.8	7.6	6.6	25	63	12
A-Bg	3½-6½"	5.7	0.07	.57	8.1	2.0	0.3	0.6	3.7	9.8	16.4	16.3	22	55	23
Btg_1	6½-16"	6.0	0.05	.45	9.0	2.1	0.3	0.7	5.4	13.2	21.7	21.3	30	39	31
Btg_2	16-24"	6.5	0.04	.44	11.0	1.2	0.3	0.5	5.7	14.4	22.1	22.3	34	37	29
Profile 2 - degrading Black															
O	3-0"	5.8	0.64	9.19	14.4										
Ah	0-4"	5.8	0.36	.46	12.8	6.0	0.2	0.9	3.2	14.3	24.6	25.2	21	62	17
Ae	4-8"	6.1	0.07	.64	9.1	2.7	0.2	0.3	2.5	7.1	12.8	11.6	22	62	16
Bt	8-13"	5.8	0.06	.55	9.2	2.4	0.3	0.6	6.0	14.3	23.6	23.6	19	49	32
Btg	13-24"	5.8	0.05	.46	9.2	2.0	0.3	0.5	5.9	14.1	22.8	23.0	30	39	31
Profile 3 - Black															
Ah_1	0-12"	6.3	0.39	4.92	12.6	3.7	0.3	0.4	5.4	22.2	32.0	31.2	26	53	21
Ah_2	12-17"	6.1	0.15	1.69	11.3	2.6	0.4	0.5	5.0	13.1	21.5	26.0	20	58	22
Ae-B	17-24"	6.3	0.06	.51	8.5	1.5	0.3	0.4	6.2	12.6	21.0	19.8	28	57	15

TABLE XIb

Analysis of Profiles from Site II

Horizon	Depth	pH	%N	%C	C/N	Exchangeable Cations m.eq./100 gm. H	Na	K	Mg	Ca	Total by Sum	CEC by Deter.	Mechanical Analysis %S	%Si	%C	% $CaCO_3$ equiv.
Profile 1-Slough Podzol																
O	3-0"	5.6	1.97	36.20	18.4											
Ahe	0-5"	5.9	0.19	2.56	13.5	4.6	0.3	0.4	2.9	6.0	14.2	14.6	25	56	19	
Aeg	5-12"	5.7	0.04	.30	7.5	1.5	0.4	0.4	1.0	1.4	4.7	4.3	26	66	8	-
Btg	12-23"	5.6	0.06	.44	7.3	2.7	0.4	1.1	6.5	12.6	23.3	24.1	17	47	36	
Bg	23-32"	5.8	0.03	.34	11.3	2.3	0.3	0.9	6.3	10.9	20.7	19.6	19	55	26	79
Dg	32-43"	6.2				1.5	0.3	0.6	5.4	8.9	16.7	15.9	23	57	20	
Dg	43-53"	7.1											32	52	16	-
Dg	53-60"	7.9											28	56	16	5.6
Profile 2 - degrading Black																
O	4-0"	6.5	1.37	23.10	16.9											
Ah	0-5"	5.1	0.17	2.23	13.1	5.8	0.2	0.2	2.8	5.0	13.8	14.2	48	33	19	
Ae	5-10"	5.5	0.02	.22	11.0	1.3	0.1	tr.	1.1	.7	3.2	3.2	60	31	9	
Bt_1	10-18"	5.6	0.06	.65	10.9	2.9	0.4	0.4	11.4	5.8	20.9	20.2	31	34	35	
Bt_2	18-31"	6.5	0.03	.46	15.3	0.7	0.5	0.4	10.0	11.2	22.8	22.5	23	41	36	
Ca	31-46"	8.0											40	29	31	
C		8.2											41	27	32	6.6
Profile 3 - thin Black																
Ah	0-4"	6.1	0.50	7.36	14.7	4.4	0.2	1.4	5.1	15.6	26.7	26.2	44	34	22	
B	4-9"	6.0	0.14	1.44	10.3	2.8	0.2	1.0	5.2	10.6	19.8	19.7	42	30	28	
B	9-16"	6.5	0.09	.80	8.9	1.1	0.3	0.8	5.7	10.2	18.1	18.0	43	29	28	
Bca	16-26"	8.1											41	29	30	
C	26"+	8.4											40	30	30	6.8

TABLE XIc

Analysis of Profile from Site III

Horizon	Depth	pH	%N	%C	C/N	Exchangeable Cations m.eq./100 gm. H	Na	K	Mg	Ca	Total CEC by Sum	Total CEC by Deter.	Mechanical Analysis %S	%Si	%C
						Profile 1 - Slough Podzol									
Aeg	1-6"	5.5	0.04	0.41	10.3	1.7	0.2	0.4	1.3	2.4	6.0	6.2	44	48	8
Btg	6-18"	5.8	0.05	0.42	8.4	2.2	0.2	1.2	5.2	10.3	19.1	19.1	36	28	26
Dg	18-26"	6.0	0.03			1.4	0.2	0.7	3.1	5.7	11.1	9.9	53	37	10

TABLE XId

Analysis of Profiles from Site IV

Horizon	Depth	pH	%N	%C	C/N	Exchangeable Cations m.eq./100 gm. H	Na	K	Mg	Ca	Total by Sum	CEC by Deter.	Mechanical Analysis %S	%Si	%C	%P	$CaCO_3$ equiv.
Profile 1 - Slough Podzol																	
O	3-0"	5.9	1.42	22.00	15.5											0.16	
Ahe	0-3"	4.9	0.35	3.83	10.9	9.2	0.4	0.9	1.8	6.2	18.5	21.0	28	52	20	0.06	
Aeg	3-8"	5.1	0.04	0.39	9.8	2.4	0.1	0.1	0.8	1.1	4.5	5.4	41	49	10	0.03	81
Btg_1	8-14"	4.8	0.06	0.55	9.2	3.8	0.9	0.4	6.5	10.4	22.0	23.1	21	40	39	0.04	
Btg_2	14-24"	4.8	0.05	0.65	13.0	3.6	1.2	0.5	7.2	13.4	25.9	26.0	11	46	43	0.05	
Btg_2	24-34"	5.1	0.05	0.58	11.6	3.0	1.2	0.3	7.4	13.6	25.5	24.3	20	41	39	0.05	
Btg_3	34-44"	6.8	0.03	0.51	17.0	0.8	1.0	0.3	6.8	13.6	22.5	25.5	35	34	31	0.05	
C_1	46-53"	7.5											35	34	31	0.06	0.7
C_2	53-60"	7.8											37	35	28		2.7
Profile 2 - black Solodized Solonetz																	
O	3-0"	6.6	1.37	21.20	15.5											0.14	
Ah	0-10"	5.8	0.45	5.20	11.6	6.4	1.7	0.6	3.6	18.0	30.3	31.4	33	44	23	0.10	
Bt_1	11-24"	6.2	0.07	0.92	13.1	1.2	5.2	0.4	4.4	13.1	24.3	23.5	38	31	31	0.04	
Bt_2	24-30"	7.4	0.06	0.87	14.5	0.0	6.9	0.5	6.0	16.3	29.7	26.7	27	34	39	0.05	
Bt_2	30-42"	7.6											12	46	42		0.5
C	46-50"	7.6											15	59	26		
C	58-62"	7.7											36	38	26	0.06	2.5

TABLE XIe

Analysis of Profiles from Site IV

Horizon	Depth	pH	%N	%C	C/N	Exchangeable Cations m.eq./100 gm. H	Na	K	Mg	Ca	Total by Sum	CEC by Deter.	Mechanical Analysis %S	%Si	%C	%P	$CaCO_3$ equiv.
Profile 1 - Slough Podzol																	
O	2½-0"	6.1	1.83	31.40	17.2											0.19	
Ahe	0-1½"	5.7	0.11	1.30	11.8	2.4	0.2	0.6	1.0	7.3	11.5	11.1	46	41	13	0.06	
Aeg_1	1½-7½"	5.9	0.03	0.30	10.8	0.8	0.1	0.4	0.8	3.2	5.3	4.8	45	45	10	0.05	
Ae-																	
Bg	7½-13"	5.7	0.03	0.27	9.0	1.4	0.1	0.6	2.6	8.6	13.3	13.3	54	24	22	0.04	
Btg_1	13-22"	5.5	0.05	0.54	10.8	2.4	0.3	0.5	4.8	13.7	21.7	23.2	31	32	37	0.05	
Btg_2	22-34"	5.7	0.04	0.57	14.3	1.4	0.3	0.3	4.8	14.0	20.8	22.0	39	27	34	0.05	
Bcag	34-44"	7.7											41	32	27	0.06	3.9
Cg	44"+	7.6											42	30	28	0.05	3.4
Profile 2 - Black																	
Ah	0-11"	6.7	0.48	5.64	11.7	2.4	0.6	1.0	6.8	29.7	40.5	41.6	9	50	41	0.05	
B	11-18"	7.4	0.13	1.39	10.7	- -	0.1	1.4	10.2	18.1	30.8	32.2	7	46	47	0.07	
Bca	18-30"	7.8	0.07										6	54	40	0.07	12.7
Bcs	30-46"	7.7	0.03										12	53	35		
C	50-54"	7.6											17	41	42		
C	68-72"	7.6											13	45	42		1.3

TABLE XIf

Analysis of Profiles from Site VI

Horizon	Depth	pH	%N	Exchangeable Cations m.eq./100 gm. H	Na	K	Mg	Ca	Total CEC by Sum	Total CEC by Deter.	Mechanical Analysis %S	%Si	%C	%P	$CaCO_3$ equiv.
Profile 1 - Slough Podzol															
O	4-0"	5.8	1.18											0.11	
Ah	0-1½"	6.1	0.65	5.5	0.4	0.6	5.2	29.3	40.9	45.0	6	50	44	0.10	
Aeg	1½-7"	7.2	0.04	0.0	0.1	0.2	1.8	6.0	8.1	8.0	12	70	18	0.06	
Bg_1	7-10"	7.0	0.06	0.1	0.3	0.5	6.7	17.8	25.4	24.0	10	37	53	0.05	
Bg_2	10-22"	7.0	0.06	0.3	0.4	0.5	6.8	23.1	31.0	29.9	14	26	60	0.06	
Bg_3	22-28"	7.1	0.06								17	25	58	0.07	0.12
Cgca	28"+	7.5									11	30	59	0.08	3.0
Profile 2 - Grey Wooded															
Ae	1-4"	5.1	0.06	4.2	0.2	0.1	1.8	2.4	8.7	9.4	22	60	18	0.03	
A-B	4-7"	4.5	0.10	8.7	0.7	0.3	7.6	5.6	22.9	22.1	16	36	48	0.04	
Bt	7-20"	4.6	0.07	7.7	1.7	0.4	12.8	9.7	32.3	33.7	10	27	63	0.05	
B	20-25"	7.2	0.09								11	29	60	0.08	
Bca	25-30"	7.6	0.08								14	30	56	0.07	3.2
C	30"+	7.6	0.08								12	34	54	0.07	2.6

TABLE XIg

Analysis of Profile from Site VII

Horizon	Depth	pH	%N	%C	C/N	Exchangeable Cations m.eq./100 gm. H	Na	K	Mg	Ca	Total CEC by Sum	by Deter.	Mechanical Analysis %S	%Si	%C
						Profile 1 - Slough Podzol									
Ahe	1½-6"	5.6	0.34	3.38	9.9	11.4	0.9	2.5	2.2	4.4	21.6	20.9	29	49	22
Aeg	6-17"	5.5	0.07	0.71	10.1	3.0	0.3	0.7	2.0	3.6	9.6	9.2	55	30	15
Bt	17-36"	5.3	0.05	0.50	10.0	2.7	0.2	1.2	5.3	10.3	19.7	20.4	42	27	31
B-C	36-50"	5.6				1.5	0.4	0.7	4.0	9.0	15.6	15.6	54	23	23
C	50-60"	5.8				1.4	0.3	0.9	5.2	14.1	21.9	22.8	39	26	35

TABLE XIh

Analysis of Profiles from Site VIII

Horizon	Depth	pH	%N	%C	C/N	H	Exchangeable Cations m.eq./100 gm. Na	K	Mg	Ca	Total by Sum	CEC by Deter.	Mechanical Analysis %S	%Si	%C
							Profile 1 - Slough Podzol								
Aeg	0-7"	5.7	0.07	0.83	11.9	2.9	0.4	0.7	1.7	4.2	9.9	9.3	14	65	21
Btg_1	7-20"	5.5	0.06	0.69	11.5	2.8	1.2	1.1	6.5	17.7	29.3	33.9	10	31	59
Btg_2	20-40"	5.5	0.05	0.67	13.4	2.4	1.2	1.0	8.4	20.0	33.0	36.4	6	40	54
Cg	40"+	6.2				1.2	1.0	0.6	7.1	15.6	25.5	27.6	8	41	51
							Profile 2 - black Solodized Solonetz								
Ah	0-10"	5.7	0.71	7.77	10.9	11.1	0.8	1.1	6.4	16.6	36.0	39.8	9	50	41
Bt	11-20"	6.8	0.13	1.84	14.2	0.9	5.6	0.5	18.4	16.0	41.4	40.2	9	43	48
C	at 44"	7.4											3	39	58

TABLE XII

A Comparison of Free Iron and Total Iron in Some Major Horizons of Associated Profiles from Various Sites

Horizon	% Free Fe_2O_3	% Total Fe_2O_3	Ratio of Total Fe_2O_3 to Free Fe_2O_3
SITE II - degrading Black			
Ae	0.44	1.42	3.2
Bt	2.01	4.54	2.3
C	1.09	3.17	2.9
SITE II - Slough Podzol			
Aeg	0.51	1.49	2.9
Btg	1.89	4.36	2.3
Bg	2.22	4.46	2.0
SITE IV - black Solodized Solonetz			
Ah	1.05	2.79	2.7
Bt	1.44	3.38	2.3
C	1.47	3.46	2.4
SITE IV - Slough Podzol			
Aeg	0.43	1.38	3.2
Btg	2.31	4.81	2.1
C	1.68	3.52	2.1
SITE VII - Slough Podzol			
Aeg	1.17	2.63	2.3
Btg	1.30	3.81	2.9
Cg	1.85	4.18	2.3
SITE VIII - black Solodized Solonetz			
Ah	1.33	3.38	2.5
Bt	1.67	5.34	3.1
C	2.16	5.68	2.6
SITE VIII - Slough Podzol			
Aeg	0.76	2.45	3.5
Btg	2.18	6.08	2.8
Cg	2.22	5.57	2.6

TABLE XIIIa

Average Exchangeable Cation Status of Profiles from Sites I and II

	Slough Podzol			degrading Black			Black	
	Aeg	Upper Btg	Lower Btg	Ae	Upper Bt	Lower Bt	Ah	B
% H^+	26	10	9	31	12	6	14	8
% Ca^{++}	40	58	59	39	45	56	63	59
% Mg^{++}	21	27	28	27	40	35	20	30
% Na^+	5	1	1	2	1	1	1	1
% K^+	8	4	3	1	2	2	2	2
C.E.C. m.eq./100 gm.	6	23	22	8	22	23	27	20

TABLE XIIIb

Average Exchangeable Cation Status of Profiles from Sites IV and VIII

	Slough Podzol			black Solodized Solonetz	
	Aeg	Upper Btg	Lower Btg	Ah	Bt
%H^+	38	12	5	26	4
% Ca^+	35	55	61	52	47
% Mg^{++}	19	26	28	15	31
% Na^+	3	4	4	4	17
% K^+	5	3	2	3	1
C.E.C m.eq./100 gm.	7	26	29	34	33

TABLE XIV

Average Exchangeable Cation Status of Seven* Slough Podzol Profiles

	Aeg		Upper Btg		Lower Btg	
	Average	Range	Average	Range	Average	Range
% H^+	30	17-45	12	8-16	7	3-12
% Ca^{++}	41	24-60	56	47-63	61	53-67
% Mg^{++}	19	15-22	26	22-29	27	25-30
% Na^+	3	2-8	2	1-4	2	1-4
% K^+	7	2-8	4	2-6	3	1-5

* Profile 2 from Site VI (Snipe) isn't included as its high base saturation isn't typical of the series (38).

TABLE XV

Average Ratios of Clay in Eluvial and Illuvial Horizons of Associated Profiles

(a) Profiles from Sites I and II

Slough Podzol		degrading Black		Black	
$\frac{Btg}{Aeg}$	3.5	$\frac{Bt}{Ae}$	3.0	$\frac{B}{Ah}$	1.3

(b) Profiles from Sites IV and VIII

Slough Podzol		black Solodized Solonetz	
$\frac{Btg}{Aeg}$	3.3	$\frac{Bt}{Ah}$	1.4

(c) Profiles from Site VI

Slough Podzol		Grey Wooded	
$\frac{Btg}{Aeg}$	3.2	$\frac{Bt}{Ae}$	3.4

Some of the analytical results shown in Tables XI to XV merit special mention because of consistent trends shown or because of apparent inconsistencies. Table XI indicates that C/N ratios in lower B horizons above the Bca reached values as high as 17. This was probably due mainly to fragments of coal in the soil. Coal is a common constituent of till in Central and Eastern Alberta. C/N ratios of Aeg and upper B horizons of Slough Podzol profiles generally indicate that oxidation of organic matter was not inhibited by reducing conditions. In general, C/N ratios are in agreement with data summarized by Russell (46). Exchangeable Na^+ percentage was usually highest in the Aeg of Slough Podzols. This is probably partially due to the weathering of minerals there as suggested by Pawluk and Bentley (39). An additional possible explanation is that the depressions in which these profiles occur may receive Na^+ bearing runoff water from adjacent slopes. This is particularly likely in areas of solonetzic soils where several of the Slough Podzols were sampled.

Although the percentage base unsaturation of the Aeg of Slough Podzols is usually highest of any horizon in the profile, its pH is generally not as low as that of upper portions of the B horizon. This is typical of Grey Wooded soils in Alberta and it is true of many degrading Black soils. The reason for this relationship is obscure.

Results of the iron analyses given in Table XII show that the free iron and total iron contents of Slough Podzol soils are similar to those of eluviated well drained soils of similar texture. It might be expected that more iron would be removed from the poorly drained soil because of reducing conditions. Bloomfield (7) showed that the grey material from a gleyed soil was very low in iron while the brown mottles were rich in iron. From this, it can be concluded indirectly that the unmottled part of Slough Podzol soil material is relatively low in free and total iron as compared with similar horizons of well drained soils. At least it is incorrect to conclude that imperfect to poor drainage conditions have no effect upon the iron status of Slough Podzols.

In several of the sampling areas it was difficult to find Slough Podzol profiles on uniform parent material. Profiles from Sites I, II, and III had D horizons. Mechanical analysis results suggest that the Slough Podzol from Site VII was not formed on uniform material. Table XIe shows that the parent materials of the two profiles from Site V were different. Because of these differences, some caution must be exercised in making direct comparisons of associated profiles. Variable texture of material deposited in the closed depressions in which Slough Podzols form is probably very common.

The B horizons of Slough Podzols which were sampled in areas of Solodized Solonetz soils had some evidence of solonetzic B characteristics. Table XIIIb shows that the average percentage exchangeable sodium in the B horizons of Slough Podzols from Sites IV and VIII was four percent. The exchangeable sodium percentage in B horizons of Slough Podzols from non-solonetzic areas was one or two percent. This may reflect one influence of parent material on the characteristics of Slough Podzols.

B. Characterization of Slough Podzols

Observations made in the field, profile descriptions and analytical results make possible a tentative general characterization of the kind of profile which has been referred to, in Alberta, as a Slough Podzol. Such a characterization follows:

Position

The Slough Podzol profile is found in depressional positions in areas of almost level to gently rolling topography. The depth of depression which favors the development of this profile decreases with increasing effective precipitation. In the Dark Brown Soil Zone, Slough Podzols are found in relatively deep depressions in areas of undulating to gently rolling topography. They are occasionally found in similar topography in the Brown zone. In the Grey Wooded soil zone such profiles are found mainly in level to depressional areas (38). Around Camrose, in the Black Soil Zone, gently undulating to undulating topo-

graphy with rather shallow depressions is typical of areas where Slough Podzols are common.

Vegetation

Aspen and willow usually comprise the dominant native vegetation in depressions where Slough Podzols occur within areas of Black and Dark Brown soils. In the Grey Wooded Zone, Slough Podzols occur under grasses and sedges as well as under trees, (38).

Climate

Since Slough Podzols are found in many soil and climatic zones, it is apparent that regional climate is not a key factor in the formation of this profile. However, Slough Podzols occupy a much greater proportion of the area in sub-humid than in semi-arid regions.

Parent Material

Slough Podzols were observed on parent materials ranging in texture from loam to clay and in mode of deposition from alluvial and lacustrine to glacial till. In the southern half of Alberta, Slough Podzols are frequently associated with solonetzic soils. Possibly the impermeable nature of the material as well as the depressional position results in a high water table which is an important factor in the development of the profile.

Drainage

Natural soil drainage refers to the rate and extent of removal of water from the soil profile in relation to the additions (54). Thus the drainage condition of a soil is a function of position, climate and permeability. These factors contribute in varying degrees to bring about the morphological evidences of imperfect to poor drainage which are observed in Slough Podzol soils.

A generalized profile description based on observations made during the course of this study follows:

Horizon	Description
O	one or more inches of decomposing organic material.
Ah and Ahe	from zero to several inches of dark brown, grey or dark grey, friable mineral material containing considerable organic material.
Aeg	from three to twelve inches of light grey, weak platy, friable, iron-mottled sandy loam to light loam.
Btg	one foot to several feet of hard, massive to blocky, mottled, clay loam to clay.
Cg	parent material of varied texture and deposition. Color is usually drab compared with well drained soils. Mottling may be almost absent.

This is similar to the Depression (Bluff) Podzols described in Saskatchewan. (37).

Some of the main features of the profile as revealed by analysis are listed:

1. pH - Characteristic pH values are: Aeg - 5.6, Btg_1 - 5.5, Btg_2 - 5.7, Cg - 6 to 7.7. These are typical of pH's of Grey Wooded soils in Alberta. (16,38).

2. Mechanical analysis - As shown by Table XV, a strongly eluviated horizon is characteristic of this profile. Well developed degrading Black and Grey Wooded soils are similar in this regard.

3. Base status - Table XIV shows that base saturation increases from about 70% in the Aeg to over 90% in the lower horizons. Exchangeable Ca^{++} increases with depth in the profile, Mg^{++} increases somewhat, while Na^{+} and K^{+} usually occupy a greater proportion of the exchange complex in the Aeg than in the B horizon. Results are similar to those reported by Pawluk and Bentley (39) for eluviated, well drained profiles.

4. C/N ratios - Average values were O-16, Aeg - 10, upper B - 10, lower B - 12. Similar C/N ratios were found for associated degrading Black soils.

5. Free iron and total iron - The ratio of total iron to free iron is generally greater in the Aeg than in lower horizons. Table XII shows the similarity in iron values for a Slough Podzol and the associated degrading Black soil.

C. Classification of Slough Podzols

According to the classification system proposed at the third conference of the National Soil Survey Committee (54) Slough or Depression Podzols are classified as follows:

Category VI	Category V	Category IV
Gleizolic soils	Grey Wooded Glei	Grey Wooded Glei peaty Grey Wooded Glei

Another possible place where some of the Slough Podzols described here could be classified is outlined:

Category VI	Category V	Category IV
Podzolic soils	Grey Wooded	imperfectly drained Grey Wooded

The decision as to which of the two possible classifications is better hinges on the drainage condition of the profile. If poorly drained, such profiles fit under Gleizolic soils; if imperfectly drained, they fit under Podzolic soils. A decision on the drainage condition of the profile depends upon the interpretation of the definitions of drainage classes set up by the conference (54). The writer favors the inclusion of the typical Slough Podzol with Gleizolic soils although some of the profiles described in the study were on the borderline between imperfectly drained and poorly drained soils.

The suitability of the name, Grey Wooded Glei, for these soils is debatable. This is clearly a better term than Slough Podzol or Depression Podzol, since the profile is certainly not a Podzol profile. However, the term Grey Wooded suggests a moderately well drained soil. Classification is complicated by the fact that analyses of Slough Podzol profiles revealed no significant differences between these and associated degrading Black and Grey Wooded soils. However, there are important differences.

1. Morphologically, Slough Podzols differ from these other soils in the following respects:

(a) There is distinct mottling in the Aeg and in lower horizons of Slough Podzols.

(b) Slough Podzols usually have drabber colors in the lower horizons than do associated well drained soils.

(c) Slough Podzols usually have a greater depth of O and/or Ah than do well drained, eluviated profiles with a similarly developed Ae horizon. However, this is not true of all the profile sequences described here.

(d) The structure of the B horizons of Slough Podzols is usually massive or coarse blocky in contrast with the well defined subangular blocky structure of Grey Wooded B horizons.

2. Eh measurements on the soil columns indicate that saturation soon gives rise to strongly reduced conditions. The depressions in which Slough Podzols occur are subjected to periodic flooding and it is probable that redox potentials within the profile fall markedly during such periods. Subsequent drying and aeration would result in oxidation and precipitation of reduced substances. If marked fluctuations in Eh do occur in these profiles, this is an important characteristic with respect to plant growth and soil development.

Because of differences in morphology, probable differences in Eh characteristics and the fact that Slough Podzols are intrazonal rather than zonal soils, the writer

feels that "Grey Wooded" should not comprise part of the name of these soils. Eluviated Glei is suggested as a possible term instead of Grey Wooded Glei in Category V. This name suggests two of the dominant features of the profile - eluviation and gleying. Several divisions would be necessary at the Category IV level to take care of differences in O, Ah, and B horizons. The following classes in Category IV are suggested:

1. peaty Eluviated Glei - several inches of peaty O.
2. Eluviated Glei (modal) - as described previously. A separation may be necessary between profiles having very little Ah and those having several inches of Ah or Ahe.
3. solonetzic Eluviated Glei - with a somewhat solonetzic B.

It is recognized that a worker in a localized area lacking familiarity with the variety of soils throughout the country should not propose major revisions in a classification system. However, he can justifiably examine the classification of soils which he has studied and suggest changes in classification and nomenclature which appear desirable as a result of his findings.

D. The Development of Slough Podzols

Results of field and laboratory studies make possible a discussion of some aspects of the development of Slough Podzols. Flooding of the depressions in which these profiles occur is a key factor in their development. Flooding fre-

quently occurs during the spring runoff and sometimes after heavy rains. The average duration of saturated conditions in these depressions is not known. Undoubtedly there would be considerable variation from year to year. The duration of saturated conditions is important since if the depression is saturated for a large proportion of the year, a marsh results. If saturated conditions be of short duration, moderately well drained profiles develop. During the period of saturation, the supply of oxygen is cut off from the profile. As organic materials are oxidized, reducing conditions develop in the profile. At such times soil constituents such as Fe and Mn are reduced and the soil solution contains an appreciable amount of the reduced form of these elements. If conditions are such that low redox potentials develop, sulfides form. Meanwhile, the excess water gradually drains downward through the profile carrying with it materials in solution. Eventually the surface water is removed by percolation, transpiration, and evaporation, and as the surface of the soil dries, upward movement of the soil solution begins. Reduced substances such as Fe^{++} are oxidized when the aerated part of the profile is reached. According to Bloomfield (6, 13) once a ferric oxide nucleus forms it acts as a surface for adsorption and subsequent oxidation of Fe^{++}. Thus the iron mottles in Slough Podzols are readily explained.

The rate of development of reducing conditions in the profile would depend partially upon temperature. If the temperature is low, microbial activity is retarded and oxidation of organic matter with resulting development of reducing conditions is slow. At temperatures in the vicinity of 20°C, reducing conditions develop rapidly after flooding as indicated by Eh measurements of column 1. Even at a temperature as low as 5°C, breakdown of organic matter continues (46). The nature and stage of decomposition of organic matter is also an important factor in determining the rate of development of reducing conditions. Because of the temperature factor, it is probable that low redox potentials would develop more rapidly after flooding of the depressions during the summer than during the spring runoff.

Loss of soil constituents by downward movement of water in the depression profiles would be partially compensated for by upward movement of the soil solution as the surface dried, by the inflow of runoff water carrying materials in solution and by the return of substances to the surface by vegetation. Possibly these factors partially account for the similarity of analytical data of Slough Podzols and associated degrading Black soils which had not been subjected to such severe leaching. If only the amount of leaching is considered, it seems logical that Slough Podzols should have a lower base status, more strongly eluviated Ae horizon and lower pH than associated eluviated soils in well drained positions.

Since the depressions in which Slough Podzols occur are frequently dry for periods of several months between floodings, it is probable that wide fluctuations in Eh and pH occur. Starkey and Wight (52) found that as aerobic conditions returned in waterlogged soils, Eh rose and pH decreased. The degree of pH change varied considerably in different soils. pH drop would be considerable in cases where $S^{=}$ was oxidized to $SO^{=}_{4}$. Results of Eh measurements of column 2 show that considerable changes in redox potential occur as the water table fluctuates even when the soil is not saturated to the surface. All the Slough Podzols studied here were sampled when the depressions in which they occurred were dry. It is likely that the pH values reported are considerably lower than they would have been had the samples been taken soon after a period of saturation.

The complexity of factors influencing the development of Slough Podzols is apparent. For a part of the year, their environment is similar to that of typical degrading Black or Grey Wooded soils. At irregular intervals, depending upon local climate, the environment changes and conditions become similar to those under which Gleizolic or Organic soils develop. Between times of saturation and aeration the environment is intermediate between these extremes. Thus it is not surprising that Slough Podzols have characteristics of both Gleizolic and Podzolic soils, and only some of the usual chemical characteristics of gleyed soils as outlined by Joffe (31) and Russell (46).

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